DETERMINATION OF FINES PRODUCED DURING CRUSHING, HANDLING, and PLACEMENT OF AGGREGATES EMPLOYED IN ROADWAY CONSTRUCTION

by

Ted S. Vinson, Robert M. Pintner, and Eric G. Johnson

Final Report
under
Contract No. 85NX167

between

Oregon State University
Transportation Research Institute

and

Alaska Department of Transportation and Public Facilities

September 1986

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-AK-RD-87-12		

4. Title and Subtitle	5. Report Date
Determination of Fines Produced During Crushing, Handling, and Placement of Aggregates Employed in Roadway Construction	September 1987
	6. Performing Organization Code
7. Author(s): Ted S. Vinson, Robert M. Pintner, Eric G. Johnson	8. Performing Organization Report No.: TRI 86-11
9. Performing Organization Name and Address: Oregon State University, Transportation Research Institute, Corvallis, OR 97331	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.: 85NX161
12. Sponsoring Agency Name and Address: State of Alaska, Dept. of Transportation & Public Facilities, Research Section, 2301 Peger Road, Fairbanks, AK	13. Type of Report and Period Covered: 21 May 1985 to 30 Sept. 1986
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The three part test procedure was developed to determine the quantity of fines produced during crushing, handling, and placement of aggregates used as base course in roadway construction. The results of the test series were compared to fines determined from field records for six aggregate sources in Alaska. These sources were associated with projects experiencing final fines contents in the roadway structure which exceeded that allowed by the State of Alaska. A comparison of the laboratory and field results indicates that the test series may overestimate the quantity of fines that is likely to be produced under normal field conditions. Presently, the three part test procedure can only be used as a conservative measure of the maximum quantity of fines that is likely to be produced for a given crushing, handling, and placement history. The nature and quantity of the fines created in the laboratory test series were analyzed in order to determine their contribution to the frost action susceptibility of a representative base course aggregate. The fines produced are predominantly in the coarse-silt (0.02 to 0.074 mm) size range. Current frost action susceptibility theories suggest that these fines alone should not render the base course aggregate frost susceptible, but fines present before crushing in combination with those produced in processing may prove to be detrimental to roadway structure performance.

17. Key Words	18. Distribution Statement
Aggregate, fines, crushing, handling, placement, processing, frost action	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	65	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ABSTRACT

The three part test procedure was developed to determine the quantity of fines produced during crushing, handling, and placement of aggregates used as base course in roadway construction. The first test simulates crushing at the quarry. It involves processing an aggregate sample of specified gradation through a small laboratory jaw crusher. The second test simulates handling by agitating an aggregate sample of specified gradation at ten percent moisture content for twenty minutes. The modified AASHTO compaction test is used to simulate placement. Following the conduct of each test in the procedure, the fines are measured by washing the aggregate over a No. 200 sieve. At the conclusion of the three part test procedure the maximum fines produced during crushing, handling, and placement are determined by summing the fines determined from each test in the series. The maximum fines produced with the procedure developed were correlated to the Washington Degradation Test results for samples obtained from six quarries in Alaska. In all cases, a poor correlation was found.

The results of the test series were compared to fines determined from field records for six aggregate sources in Alaska. These sources were associated with projects experiencing final fines contents in the roadway structure which exceeded that allowed by the State of Alaska. A comparison of the laboratory and field results indicates that the test series may overestimate the quantity of fines that is likely to be produced under normal field conditions. However, owing to the lack of a large body of well-documented field data, it is not possible to reach a definitive conclusion at this time. Presently, the three part test procedure can only be used as a conservative measure of the maximum quantity of fines that is likely to be produced for a given crushing, handling, and placement history.

The nature and quantity of the fines created in the laboratory test series were analyzed in order to determine their contribution to the frost action susceptibility of a representative base course aggregate. The fines produced are predominantly in the coarse-silt (0.02 to 0.074 mm) size range. Current frost action susceptibility theories suggest that these fines alone should not render the base course aggregate frost susceptible, but fines present before crushing in combination with those produced in processing may prove to be detrimental to roadway structure performance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

This project report is a compilation of two articles written for separate publication and inclusion herein. Each paper is complete by itself. There is some duplication in the background material in the papers. Citations in the text refer to references listed at the end of each chapter. These references are collected into a comprehensive bibliography at the end of the report.

1.0 INTRODUCTION

The Alaska Department of Transporation and Public Facilities (ADOT&PF) employs the fines content (material passing the No. 200 sieve) of aggregates in the design of its asphalt pavements. In order to design a durable and economically feasible pavement, it is necessary to be able to predict the final fines content of the aggregate being employed for base and subbase courses. Because of the scarcity of durable aggregate in Alaska, the ADOT&PF has utilized aggregate of marginal quality. While the ADOT&PF recognizes these marginal sources and quantifies the severity of the problem with the Alaska T-13 Degradation Test (Washington Degradation Test), the relationship between the degradation value obtained and the final fines content is not known. Further, no means exists for predicting the quantity of fines that are produced during crushing, handling, and placement.

In 1980, the ADOT&PF Research Section completed a three-year study of the performance of 120 existing pavement sections (McHattie et al. 1980). From an evaluation of these sections it was determined that fines content was the best indicator of pavement design life and an empirical pavement design procedure was developed based on fines content. The base course aggregates were found to have a dramatic loss of strength on thawing when the fines content became larger than a critical value which increases with depth. The fines content of a marginal aggregate, if greater than this critical value, could add 3 inches (7.6 cm) to the design pavement thickness on a typical project and increase the project cost by several million dollars.

In order to improve on understanding of the production of fines during aggregate processing, a research study was undertaken with the following objectives: 1) Develop laboratory techniques that simulate the fines production experienced during crushing, handling, and placement of aggregates;

2) Establish a correlation between standard degradation test results and the production of fines during crushing, handling, and placement of aggregates; 3) Establish the characteristics of the fines produced, and the implications with respect to frost action potential in roadway aggregates. The results from the study are presented herein.

1.1 REFERENCES

1. McHattie, R.L., Connor, B.G., and Esch, D.C., "Pavement Structure Evaluation of Alaskan Highways," Report No. FHWA-AK-RD-81-7, Federal Highway Administration, March, 1980.

2.0 QUANTITY OF FINES PRODUCED DURING CRUSHING, HANDLING, AND PLACEMENT OF ROADWAY AGGREGATES

by

Robert M. Pintner[1], Ted S. Vinson[2], and Eric G. Johnson[3]

ABSTRACT: A three part test procedure was developed to determine the quantity of fines produced during crushing, handling, and placement of aggregates used as base course in roadway construction. The first test simulates crushing at the aggregate source. It involves processing an aggregate sample of specified gradation through a small laboratory jaw crusher. The second test simulates handling by agitating an aggregate sample of specified gradation at ten percent moisture content for twenty minutes. The modified AASHTO compaction test is used to simulate placement. Following the conduct of each test in the procedure, the fines are measured by washing the aggregate over a No. 200 sieve. At the conclusion of the three part test procedure the maximum fines produced during crushing, handling, and placement are determined by summing the fines determined from each test in the series. The maximum fines produced with the procedure developed were correlated to with the Washington Degradation Test results for samples obtained from six aggregate sources in Alaska. In all cases, a poor correlation was found. Owing to the lack of a large body of well-documented field data, the three part test procedure can only be used at this time to determine the maximum quantity of fines that is likely to be produced for a given crushing, handling, and placement history.

[1] Staff Engineer, San Diego Soils Engineering, Inc., San Diego, California 92111. Formerly Graduate Research Assistant, Oregon State University, Corvallis, Oregon 97331.

[2] Professor of Civil Engineering, Oregon State University, Corvallis, Oregon 97331.

[3] Geotechnical Engineer, Alaska Department of Transportation and Public Facilities, Anchorage, Alaska 99502.

2.1 INTRODUCTION

Highway engineers have long recognized that detrimental fines (material passing the No. 200 (0.074 mm) sieve) are produced during crushing, stock-piling, transportation of aggregate to a jobsite, and placement (i.e. compaction) of the aggregate during roadway construction. Indeed, the fines that are generated during crushing, handling, and placement can render the material unacceptable (based on a percentage of allowable fines) for roadway construction. Fines in the base course result in poor drainage, increased tendency to rut and, in cold regions, frost action (i.e. frost heave and thaw weakening).

At the present time, the final fines content for a given history of crushing, handling, and placement cannot be predicted. Further, the relationship between standard degradation tests and the final fines content is not well understood. In recognition of the need to predict the final fines content of a base course material for a given crushing, handling, and placement history a research study was undertaken with the following objectives: 1) Develop laboratory techniques that simulate the degradation experienced during crushing, handling, and placement of aggregates; 2) Establish a correlation between standard degradation test results and the production of fines during crushing, handling, and placement of aggregates. The results of this study are reported herein. An appreciation of the test results is enhanced by reviewing previous work related to the production of fines during aggregate processing, and degradation testing of aggregates. This review is provided in the following sections.

2.2 PRODUCTION OF FINES DURING AGGREGATE PROCESSING

No detailed study has been conducted to evaluate the production of fines which occurs during the crushing and handling processes. In an unpublished preliminary study, Slater [1] examined the quality of an aggregate source in Alaska. The rock consisted of phyllites and slightly metamorphosed greywacke. When crushed in a laboratory crusher a maximum increase in fines of only 2 percent was noted. Slater concluded from this that the aggregate does not produce significant amounts of fines during crushing. To simulate handling, the aggregate was shaken in a stainless steel container with a Tyler sieve shaker for five minutes. Only insignificant amounts of fines were produced when the aggregate was tested in a dry state. When tested at 5 percent moisture content, as much as 5 percent fines were produced. Slater concluded that significant quantities of fines were likely to be produced during handling of this aggregate. As a control, a durable aggregate (Tanana River gravel) was tested in the same manner. At 5 percent moisture content a maximum of 0.8 percent fines was produced.

Aughenbaugh et al. [2] considered a glacial gravel (containing a variety of rock types) in a study to evaluate the degradation that occurs during the placement and compaction of a base course. Field tests were performed with three types of compactors (steel-wheel roller, vibratory roller, and pneumatic rubber-tired). A direct relationship was observed between the amount of degradation and the initial grading of an aggregate. Uniform gradings experienced more general breakdown than dense gradings, but no significant difference in the amount of fines produced was observed. Most degradation occurs in the top of the lift during the first compaction pass, and decreases with each subsequent pass. After evaluating several laboratory tests, including the Los Angeles Abrasion, mechanical kneading compactor, repetitive loading, modified AASHTO, freeze-thaw, and absorption and specific gravity, Aughenbaugh et al. concluded that there is no single physical test or combination of tests that may be used to evaluate production of fines for all aggregate types and construction histories. Of all the tests evaluated, only the Los Angeles Abrasion test showed promise of being useful.

Hoover et al. [3] also studied the degradation of base course aggregates subjected to various types of laboratory compaction. They concluded that at a particular combination of frequency, amplitude, surcharge weight, and duration, vibratory compaction produced little or no visible breakdown. Other methods, including standard and modified AASHTO compaction, static compaction, and drop hammer compaction (i.e., molding an entire, non-layered specimen by drop hammering on both top and bottom), produced significant degradation in aggregates with good service records. The rock sources for this study consisted of two limestone sources, and one dolomite source.

Szymoniak [4] employed repeated load cyclic triaxial tests to determine the production of fines associated with traffic loadings in base course basalt aggregates. The fines content increased on average from an initial value of 1.6 percent to a final value of 2.5 percent after 100,000 cycles of loading. The results indicate that traffic loading does not produce substantial increases in fines.

2.3 DEGRADATION TESTING OF AGGREGATES

Aggregate degradation may be defined as the breakdown of aggregate pieces into smaller particles through physical and/or chemical processes. Physical, or mechanical, degradation is associated with the fracture and abrasion of aggregate particles. Chemical degradation is the breakdown of rock by some chemical process. Chemical changes occur over long time spans. For purposes of this study, it is assumed that mechanical degradation is solely responsible for production of fines during crushing, handling, and placement of aggregate.

Degradation is influenced by the physical properties of the rock and the environmental conditions surrounding the rock. Physical properties of the rock include strength, primary and secondary mineral composition, structure, and texture. Environmental conditions include weather, traffic, access to moisture, temperature changes, gradation, degree of compaction, and bearing strength of the subgrade.

The problem of aggregate degradation was first addressed in the early 1900's, but it was not until the mid-1930's that attempts were made to simulate field conditions in the laboratory and develop tests to determine aggregate quality [5,6]. Rothgery [7] determined that the Los Angeles Abrasion Test was a practical means of testing aggregates. Much work was done in the field of aggregate durability in the late 1940's and early 1950's. However, these studies were generally concerned with aggregate for concrete or asphalt pavement.

The early degradation tests were based on the impact and abrasion of dry aggregates. The type of fines produced in these tests were not necessarily similar to those produced in the field. In the 1950's a number of Western states developed tests which degraded the aggregate in water and measured the fines as the height of sediment in a settling tube, thus giving an indication of the type of fines produced. These tests include the Washington and Oregon Degradation and California Durability tests.

Lund [8] correlated the field performance of base course aggregates, for twelve aggregate sources of varying lithology, with Los Angeles Abrasion, Sodium Sulfate Soundness, Oregon Degradation, California Durability, and Washington Degradation test results. Results from the Washington Degradation had the best correlation, California Durability and Oregon Degradation were good, while Los Angeles Abrasion and Sodium Sulfate Soundness had low correlations with field performance.

An extensive evaluation of degradation tests for base course aggregates was undertaken by West et al. [9]. Aggregate samples were collected from 140 aggregate sources in twelve states. Determinations were made for most of the samples of: (1) percent loss by Los Angeles Abrasion, (2) freeze-thaw loss, (3) specific gravity, (4) percent absorption, (5) insoluble residue, (6) differential thermal analysis, (7) x-ray diffraction analysis, and (8) petrographic analysis, including (a) polished section, and (b) thin-section textural characteristics. The samples were divided into three groups: No. 1-carbonate and clastic sedimentary rocks, and coarse-grained igneous and metamorphic rocks, No. 2-basalt and other fine-grained igneous and metamorphic rocks, and No. 3-heterogeneous gravels. A test procedure to evaluate aggregate characteristics was defined for each group. Tests for group No. 1 include Los Angeles Abrasion, freeze-thaw, and megascopic petrographic analysis for grain size and orientation. Tests for group No. 2 include wet and dry Los Angeles Abrasion, freeze-thaw, and complete petrographic analysis. Tests for group No. 3 include Los Angeles Abrasion, freeze-thaw, and megascopic petrographic analysis.

Many attempts have been made to use petrographic analysis as a means of determining the degradation characteristics of aggregates [9,10,11,12]. Based on a study of the geological properties influencing the polishing characteristics of road surface aggregates, Hartely [13] concluded that the complex nature of the minerals and their bonding is such that petrography cannot be used as a sole means of assessing rock quality. In a study of the chemical degradation of basalts, Van Atta and Ludowise [14] concluded that the durability of aggregates could not be determined solely by the percentages of secondary minerals found in rocks. The durability was, however, related to certain combinations of minerals present in the rock and the textural distribution of swelling clays in the rock matrix. This is substantiated through work presented by Cole and Sandy [15]. They proposed the Secondary Mineral Rating System which incorporates the type of deleterious minerals, their quantity, and textural distribution within the rock fabric, to identify the durability of basalt aggregate.

2.4 SAMPLE COLLECTION

Aggregate samples for the study were provided by the Alaska Department of Transportation and Public Facilities (ADOT&PF). The samples consisted of unprocessed rock from nineteen rock sources in Alaska. All of the sources had been used in roadways, many of which experienced poor performance due to excessive fines produced during crushing, handling, and placement. To supplement the Alaskan samples, a rock source in Oregon was also identified (Umpqua Sandstone). Brief descriptions of the samples from all sources are given in Table 2.1.

2.5 CRUSHING

All of the laboratory crushing was done with a Braun Chipmunk jaw--crusher. This is a very common crusher found in commercial and government aggregate laboratories. The crusher has a fixed jaw and a reciprocating jaw, as illustrated in Figure 2.1. The maximum jaw opening can be varied from 1.3 to 2.5 cm (0.5 to 1.0 in.).

Initial crushing tests were performed on five aggregates with the goal of producing material that met ADOT&PF specifications for base course aggre

Table 2.1 Aggregate Source Descriptions

Source Number and/or Name	Rock Type
371-001-2, MP 315.5 Parks Hwy.	Schist and Quartzite (pit)
71-1-003-5, Wagon Point	Phyllite and Metagreywacke (pit)
71-1-030-5, MP 47.7 Richardson Hwy.	Phyllite and Metagreywacke (pit)
71-1-034-5, MP 63.4 Richardson Hwy.	Phyllite and Metagreywacke (pit)
71-1-036-5, Ptarmigan Creek	Phyllite and Metagreywacke (pit)
31-1-012-1, MP 42 Seward Hwy.	Metagreywacke (pit)
21-2-399-1, MP 62.9 Sterling Hwy.	Metagreywacke (pit)
391-001-1, Russian River	Phyllite (pit)
680-111-2, Chatanika River	Quartzite and Schist (pit)
680-094-2, MP 6 Elliott Hwy.	Schist (quarry)
621-007-5, Paradise Hills	Amphibolite (quarry)
371-156-2, MP 317.5 Parks Hwy.	Schist and Quartzite (pit)
Lemon Creek	Granitic and Some Schist (pit)
Taylor South	Granitic (quarry)
Taylor North	Welded Tuff (quarry)
Brown's Hill	Basalt (quarry)
Umpqua Sandstone	Moderately Well Cemented Sandstone (quarry)

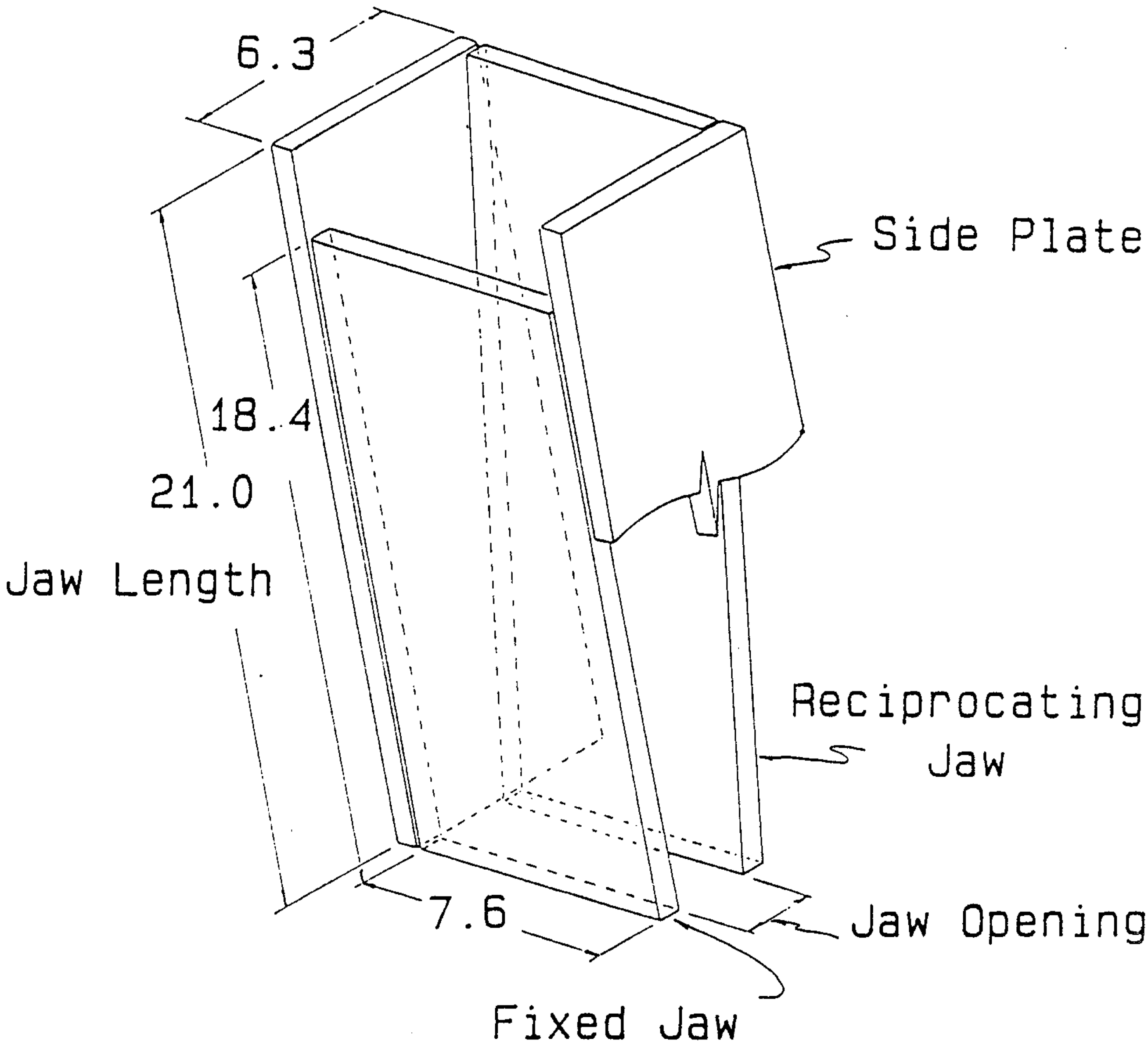


FIGURE 2.1 -- SCHEMATIC OF BRAUN CHIPMUNK CRUSHER JAWS (DIMENSIONS IN cm).

gate. It was reasoned that crushing to this specification should produce quantities of fines likely to occur during field production. Clean, plus 19 mm (0.75 in.) rock was crushed at jaw openings of 1.3 and 1.9 cm (0.5 and 0.75 in.). Figure 2.2 shows typical product gradation curves for the two jaw openings. It was apparent at this stage in the testing that the crusher tended to produce a poorly graded material. The 1.3 cm (0.5 in.) opening produced gradations deficient in the plus 13 mm (0.5 in.) and minus 4.8 mm (No. 4 sieve) sizes. At the 1.9 cm (0.75 in.) opening, the plus 13 mm (0.5 in.) fraction was acceptable, but the product was very deficient in the minus 4.8 mm (No. 4 sieve) size. The bulk of the material was of a size slightly smaller than the jaw opening.

Lowrison [15] argued that the shorter the jaw length, the more uniform the product. The effect of the jaw movement is both to crush and break, thereby increasing the voids between pieces, and to compress and compact, thereby decreasing the voids. Since both of these effects occur simultaneously, it is difficult to predict the final bulk density, but the tendency must be to increase bulk density. The greater the jaw length, the greater the tendency for compaction and, therefore, production of a well-graded material.

Several attempts were made to produce specification gradation material by crushing the material twice either at the same jaw opening or at two different jaw openings. In general, the result was to satisfy the minus 4.8 mm (No. 4 sieve) requirement, but to be deficient in the plus 13 mm (0.5 in.) size.

In a final attempt to produce specification gradation material, unsieved specimens representative of the entire range of grain sizes of each of the original samples, were crushed. In one case, specification gradation was achieved but, in general, the product was deficient in the plus 13 mm (0.5 in.) size.

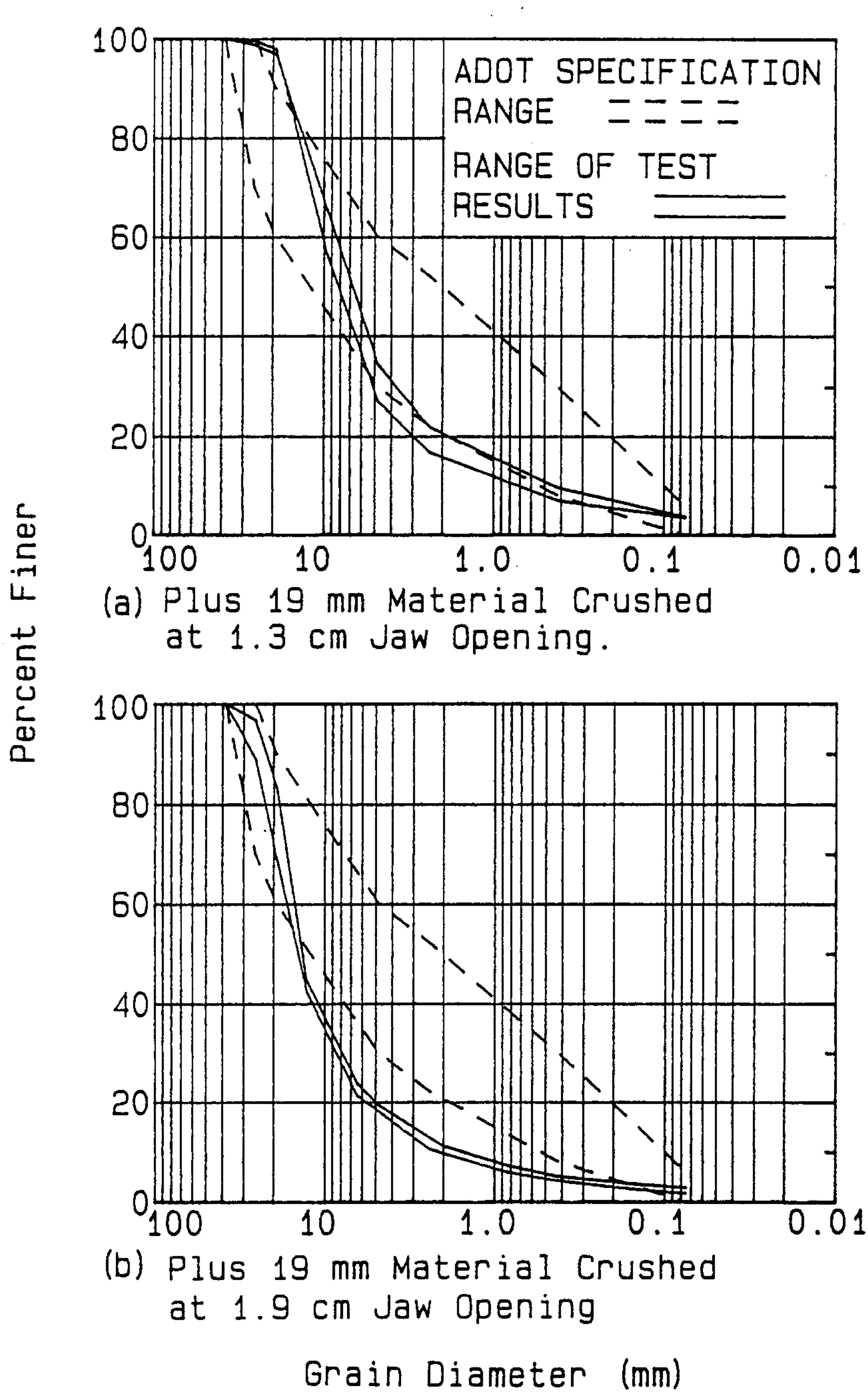


FIGURE 2.2 -- JAW CRUSHER PRODUCT GRADATION CURVES.

It may be concluded from the results presented that it is not possible to consistently produce specification gradation material with a small laboratory jaw crusher. As no other crusher was available, it was necessary to proceed in a different manner. Instead of attempting to produce specification gradation, it was decided that a simple test should be developed to determine the fines production potential of a particular aggregate during crushing. In order for the test to be reproducible, it would be necessary to eliminate all factors that affect the fines production, so that the only variable would be the lithology of the feed (i.e. rock source) material.

Many factors influence the product size: feed size, feed gradation, feed material lithology, feed rate, jaw opening, rate of crushing, range of jaw motion, and jaw length. The last four factors are a function of the type of crusher used and are therefore constant in this study. The rate of feed input could be controlled to a limited extent. In order to keep the feed rate constant, a hopper was constructed so that the jaws always remained full. This facilitated the process in two ways. First, the feed rate would always be equal to the rate of discharge; second, the tendency of the jaw action to decrease the voids is greater and, therefore, the range of particle sizes produced should be greater. The use of the hopper restricted the size of material that could be crushed to less than 25 mm (1.0 in.). Particles larger than 25 mm (1.0 in.) tended to get caught in the bottom of the hopper. The character of the feed material was controlled by using the same rock source, specifically the Umpqua Sandstone.

The results from the initial set of crushing tests indicated that the gradation produced from crushing the plus 19 mm (0.75 in.) material is independent of rock type. Based on this fact, it was hypothesized that the effects of initial gradation on the amount of fines produced could be eliminated by crushing large rocks and then recrushing the material using the hopper. The fines production potential of the rock would be taken as the increase of fines from the first crushing to the second crushing. The test was performed by crushing the large rock at a jaw opening of 1.9 cm (0.75 in.). Recrushing was performed at a 1.3 cm (0.5 in.) jaw opening. The results from eight tests on Umpqua Sandstone following the procedure are given in Table 2.2. The mean change in fines is 0.35 percent with a standard deviation of 0.16 percent, making the procedure unacceptable. This large standard deviation is partly due to the fact that the increase in fines is very small and thus small variations will cause the percent error to be large. There is also a large variation in the amount of fines after the first crushing. This may be due to the variation in the size and lithology of the feed material. Because the feed size range was great, 76 to 19 mm (3.0 to 0.75 in.), there was a possibility for quite a bit of variation in gradation between samples. Although the sandstone used for this test was fairly homogeneous, there was some variation between samples, especially with respect to the degree of weathering.

To make the test as reproducible as possible, a maximum amount of fines should be produced. At the same time, the loss of fines should be minimized. Therefore a procedure that limits the amount of handling and processing associated with crushing is desirable. This requirement eliminates the possibility of crushing the material twice, even though it would increase the amount of fines, it could greatly increase the error due to loss of fines. In order to maximize the quantity of fines produced with one crushing, all or most of the feed material must be larger than the jaw opening. In this

Table 2.2 Fines Produced from Umpqua Sandstone Crushed at 1.9 cm (0.75 in.) Jaw Opening and Recrushed at 1.3 cm (0.5 in.) Jaw Opening

Trial No.	Percent Fines		
	First Crushing	Second Crushing	Difference
1	1.4	1.7	0.3
2	1.3	1.9	0.6
3	1.5	1.9	0.4
4	1.8	2.0	0.2
5	1.7	1.8	0.1
6	1.6	2.1	0.5
7	1.3	1.7	0.4
8	2.1	1.6	0.4
Mean	1.5	1.8	0.3
Standard Deviation	0.2	0.2	0.2

way it is assured that little or no material passes through the crusher without being crushed. To reduce the sample variation problem a large sample was crushed with the jaws at their widest opening. The product was sieved into various size fractions. Following this procedure it was possible to perform tests on any of the fractions with the assurance that the test sample is representative of the whole sample.

The 10 to 19 mm (0.38 to 0.75 in.) particle size was chosen for the crushing test. As previously noted, the use of the hopper limits the size to material smaller than 25 mm (1.0 in.). The smallest jaw opening is 1.3 cm (0.5 in.), so the minimum size should not be much less than 13 mm (0.5 in.). When set at its largest opening the crusher produces an abundance of 10 to 19 mm (0.38 to 0.75 in.) material. The use of this size range in the crushing test satisfies the above criteria, and it is easy to produce.

The final crushing procedure employed for the study is as follows:

1) Crush a minimum of 23 kg (50 lbs) of plus 19 mm (0.75 in.) material at the 2.5 cm (1 in.) jaw opening;
2) Separate the 10 to 19 mm (0.38 to 0.75 in.) fraction; wash and dry the material at 110°C to a constant weight;
3) Weigh out a 3000±10 g (6.62±0.02 lbs) sample;
4) Set the jaw opening to 1.3 cm (0.5 in.); quickly dump the sample into the hopper with the crusher running;
5) Split the product into two parts with a sample splitter; weigh each part to the nearest 0.05 g;
6) Wash each part over a No. 200 sieve; be sure to remove all of the fines;

7) Dry the washed material at 110°C to a constant weight, and weigh to the nearest 0.05 g;

8) Calculate the percent loss of fines for each part; take the average of the two parts as the loss for the entire 3000 g (6.62 lbs) sample; repeat steps 3 through 8 a minimum of three times.

The results obtained with this test procedure for three separate trials with Umpqua Sandstone are given in Table 2.3. The small standard deviation within each trial indicates that the procedure is reliable. The difference in the mean percent fines between trials indicates that the variability of the rock is an important factor even with a relatively homogeneous material. Once the repeatability of the test was demonstrated, the test was performed on samples from nineteen aggregate sources in Alaska. The results are given in Table 2.4. The range of percent fines produced during crushing is small. The lowest value is 1.3 percent, and the greatest was 3.5 percent. Only three samples produced more than 2.5 percent fines, and only two produced less than 1.5 percent, leaving fourteen samples within 1 percent of each other.

2.6 HANDLING

The degradation that occurs during handling of an aggregate is substantially different than that which occurs during crushing. The crushing process develops stresses in the rock which cause failure. The failure produces particles of various sizes, including fines. The handling process on the other hand produces fines by abrasion and impact. Consequently, a laboratory procedure that simulates handling must produce fines by abrasion and impact. Degradation tests such as the Los Angeles (L.A.) Abrasion test (ASTM C131) and the Washington Degradation test (WSHD 113A) both produce fines by abrasion.

Table 2.3 Fines Produced from 10 to 19 mm (0.38 to 0.75 in.) Umpqua Sandstone Crushed at the 1.3 cm (0.5 in.) Jaw Opening

Trial No.	Crushing No.	Percent Fines	Mean	Standard Deviation
	1	2.2		
1	2	2.2	2.2	0.1
	3	2.3		
	1	1.9		
2	2	1.7	1.8	0.1
	3	1.8		
	1	2.6		
3	2	2.7	2.6	0.1
	3	2.5		

Table 2.4 Fines Produced During Crushing of Aggregate Samples

Source Number and/or Name	Percent Fines	Washington Degradation Value
371-001-2, MP 315.5 Parks Hwy.	2.2	29
371-001-2 (Schist)	2.3	14
371-001-2 (Quartzite)	2.3	78
71-1-003-5, Wagon Point	3.1	27
71-1-030-5, MP 47.7 Richardson Hwy.	3.5	31
71-1-034-5, MP 63.4 Richardson Hwy.	2.4	42
71-1-036-5, Ptarmigan Creek	2.1	51
31-1-012-1, MP 42 Seward Hwy.	1.4	43
21-2-399-1, MP 62.9 Sterling Hwy.	1.3	60
391-001-1, Russian River	1.8	37
680-111-2, Chatanika River	2.4	80
680-094-2, MP 6 Elliott Hwy.	2.7	35
621-007-5, Paradise Hills	2.2	71
371-156-2, MP 317.5 Parks Hwy.	2.1	53
Lemon Creek	1.5	41
Taylor South	1.4	52
Taylor North	1.5	49
Brown's Hill	1.8	60
Umpqua Sandstone	2.2	1

In the L.A. Abrasion test, however, the aggregate falls onto the bottom of the steel drum, and is impacted by steel balls, while in the Washington Degradation test, the aggregate is agitated in a plastic container, and much less impact is involved. Owing to the greater impact the L.A. Abrasion test, or a modification thereof, may be more appropriate for simulating the production of maximum fines during handling.

Another factor that must be recognized is the condition of the aggregate during handling. In the field the crushed rock aggregate is not dry. In a preliminary study of the quality of an aggregate source in Alaska, Slater [1] found that the moisture content of the laboratory sample has a pronounced effect on fines production. The test procedure employed in the study consisted of shaking a sample for 5 minutes with a Tyler sieve shaker at 300 cycles per minute. The sample was placed in a stainless steel container. Slater suggested that this procedure results in a test that is not especially harsh, but one which may be indicative of degradation during a moderate amount of handling. A nine-fold increase in fines production was noted when the aggregate was tested at 5 percent moisture content compared to when it was tested dry. Based on this result, it was recommended that the test be conducted on material in a moist condition.

The L.A. Abrasion test was modified by removing the steel balls. It was believed that the test would better simulate handling without the balls, because the balls tend to crush the rock more than is likely to occur in the field. A pilot study was conducted with the modified L.A. Abrasion test with Umpqua Sandstone at 5 percent moisture content. After less than 100 revolutions all of the sand size particles adhered to the walls of the drum and were thus no longer experiencing degradation. Also, removal of the finer fraction material from the apparatus proved to be difficult. A large quantity of water was required, and it was impossible to retain all of the material. For these reasons the modified L.A. Abrasion test was eliminated as a possibility for simulating the handling process.

Considering these results, a decision was made to use the test suggested by Slater [1] to simulate handling. Six aggregate sources were chosen for testing, including the source considered by Slater. A sample from each source was tested dry, and at 5 and 10 percent moisture contents. The moist samples were also subjected to twenty minutes of shaking as well as the specified five minute period. The test procedure employed was as follows:

1) Weigh out, to the nearest gram, the portions of washed and oven dried crushed aggregate indicated in Table 2.5.
2) Place the material in a watertight container; blend gently, but completely with the desired amount of water, cover and let stand for at least four hours;
3) Transfer the material to a 38 cm^3 (1 gal.), 21 cm (8.25 in.) diameter, stainless steel container; cover and shake with a Tyler sieve shaker at 300 cycles/min for the desired time;
4) Wash the material from the container into a pan; dry at 110°C to a constant weight;
5) Weigh the dried material to the nearest 0.05 g; wash the material over a No. 200 sieve and dry at 110°C to a constant weight;
6) Weigh the washed and dried material to the nearest 0.05 g; calculate the percent loss of fines.

Table 2.5 Portions of Washed and Oven Dried Crushed Aggregate Employed in Test Procedure

Size Fraction in mm (inches or sieve size)	Amount in grams (lbs.)
25 to 19 (1.0 to .75)	150 (0.33)
19 to 10 (0.75 to 0.38)	200 (0.44)
10 to 4.8 (0.38 to No. 4)	150 (0.33)
4.8 to 2.4 (No. 4 to No. 8)	150 (0.33)
2.4 to 0.4 (No. 8 to No. 40)	200 (0.44)
0.4 to 0.07 (No. 40 to No. 200)	150 (0.33)

The results from the handling tests for six aggregate sources are shown on Figure 2.3. Clearly the effect of increased water content is to increase the fines production for all of the aggregate sources. When tested dry, none of the samples produced a significant amount of fines; the average value was only 0.5 percent. When performed at 5 percent moisture content for 5 minutes, the average amount of fines increased to 1.2 percent. With 10 percent moisture content, for 5 minutes, the average was 2.0 percent. The amount of fines also increased when the test was performed for longer time periods. At 5 percent moisture content for 20 minutes, the average was 1.6 percent (an increase of 0.4 percent from the 5 minute test). At 10 percent moisture content for 20 minutes, the average was 3.8 percent (an increase of 1.8 percent from the 5 minute test). The greater increase for the samples at 10 percent moisture content may be caused by the tendency of the sample to adhere to the sides of the container when tested for the longer duration at the low moisture content. Sample 71-1-030-5 was from the same source as the samples tested by Slater [1]. The results are not in good agreement with those given by Slater. The discrepancy could be due to lithologic differences in the samples employed or a difference in the gradation of the test sample. The gradations for the samples Slater used were not given.

2.7 PLACEMENT

Modified and Standard AASHTO compaction tests (ASTM D 698-70) and (D 1557-70) were used to simulate production of fines during aggregate placement (compaction). In the modified compaction test the compactive energy per volume is 56,300 ft-lb/cu. ft., whereas in the standard compaction test it is 12,400 ft-lb/cu.ft. The samples had the same gradation as those employed in the handling test. All of the tests were performed at 5 percent moisture

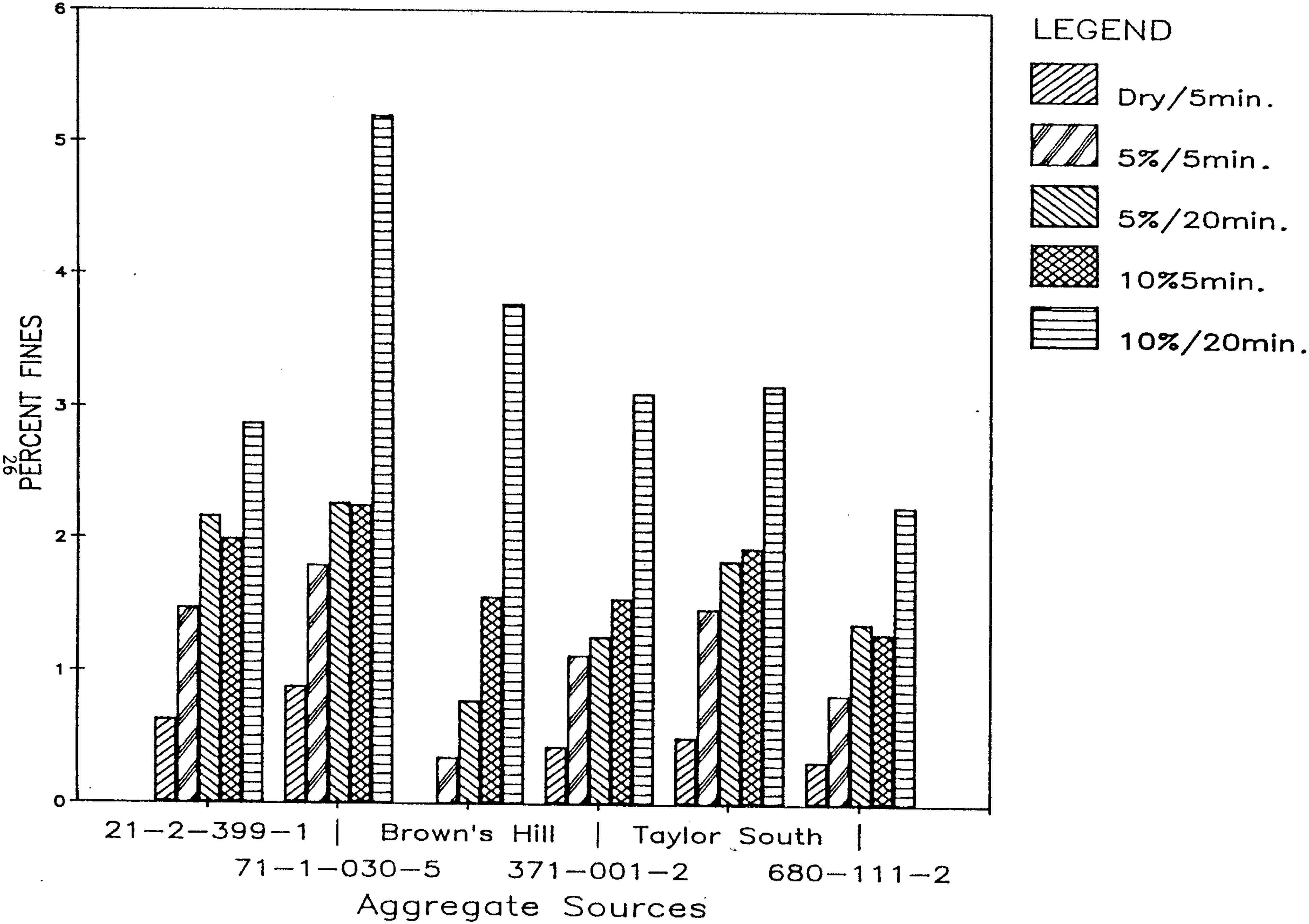


FIGURE 2.3. -- FINES PRODUCED FROM HANDLING TESTS FOR SIX AGGREGATE SOURCES.

content. The results of the tests are given in Table 2.6. In general, the standard AASHTO compaction test produced only moderate amounts of fines, generally between 1 percent and 2 percent. The modified AASHTO test generally produced between 2 percent and 3 percent fines. This may be considered a significant degree of degradation, but the test results do not allow differentiation between samples. Only source 71-1-030-5 showed a greater amount of fines production compared to the other samples. Source 71-1-030-5 also experienced the greatest fines production in the crushing and handling tests.

2.8 DEGRADATION TESTING

The three part test procedure presented in the preceding sections is time consuming. It would be easier to use a single test to predict the fines produced from all three processes. The purpose of this section is to establish a correlation between the crushing, handling, and placement tests with standard degradation tests.

The Washington Degradation Test was selected for correlation with the quantity of fines produced in the crushing, handling, and placement tests. As previously noted, Lund [8] established that the Washington Degradation Test had the strongest correlation with field performance when compared to five other degradation tests considered. The Washington Degradation value is a rating of the aggregate from 0 (poor) to 100 (excellent).

Figure 2.4 presents a comparison of the fines produced during crushing and the Washington Degradation value. The correlation is poor. The lack of correlation is probably due to the difference in the mechanisms that act to produce the fines in the two tests. In some cases, such as samples composed primarily of quartzite, the degradation value was quite high (70 to 80), but greater than average amounts of fines are produced. In the degradation test

Table 2.6 Fines Produced from Compaction Tests for Six Aggregate Sources

Source Number and/or Name	Percent Fines	
	Standard AASHTO	Modified AASHTO
371-001-2, MP 315.5 Parks Hwy.	1.2	2.9
21-2-399-1, MP 62.9 Sterling Hwy.	1.6.	2.3
680-111-2, Chatanika River	0.8	2.3
71-1-030-5, MP 47.7 Richardson Hwy.	2.3	4.4
Taylor South	1.2	2.2
Brown's Hill	1.8	2.7

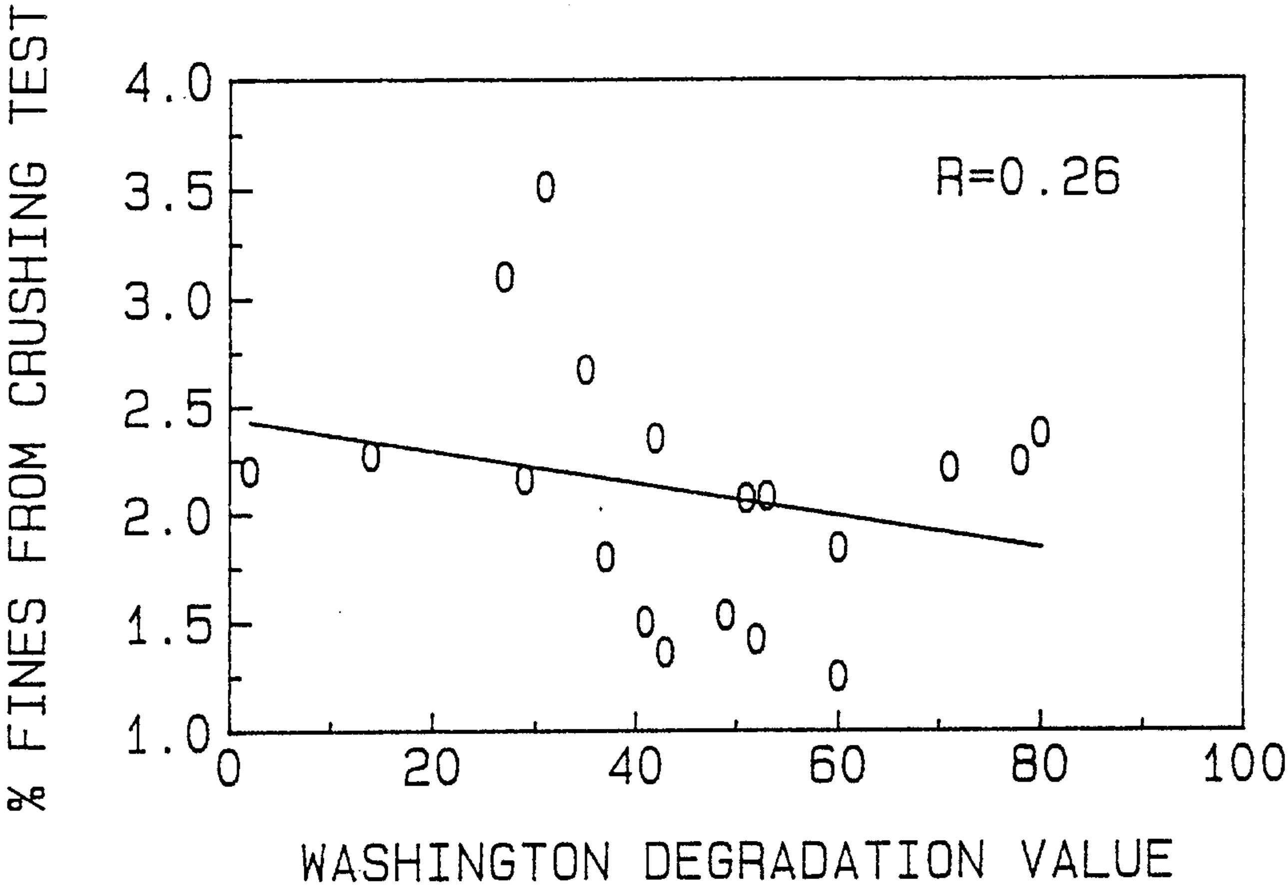


FIGURE 2.4. -- FINES PRODUCED FROM CRUSHING TEST VERSUS WASHINGTON DEGRADATION VALUE.

quartzite, due to its hardness, is highly resistant to abrasion. In the crushing process, however, the rock undergoes a brittle failure which produces fine rock fragments.

In addition to the effect of the different mechanisms of fines production, the method of measuring the fines may influence the correlation. In the crushing test, the quantity of fines produced is measured through wash sieving, and the percent by weight of fines is determined. In the degradation test, the fines are placed in a settling tube with a flocculating agent, and the sediment height is measured after twenty minutes. The same weight of fines with different percentages of clay sizes will settle to different heights due to their different rates of settlement. With this method lower degradation values will be assigned to material producing more clay size particles. In other words, the degradation value not only reflects the quantity of fines, but also the gradation of the fines.

The correlations between the fines produced in the handling tests and the Washington degradation value are shown in Figure 2.5. Again, the correlations are poor. Because the mechanism of fines production in the handling and the degradation tests are the same, a much better correlation was expected. The differences between the handling and degradation tests are the amount of water, the duration of agitation, and the method of measuring the fines as discussed with respect to the crushing test. The best correlation was associated with the handling test performed at 10 percent moisture content for 20 minutes. This test is most like the degradation test in terms of moisture content and duration, indicating that moisture content and duration may have an effect on the correlations.

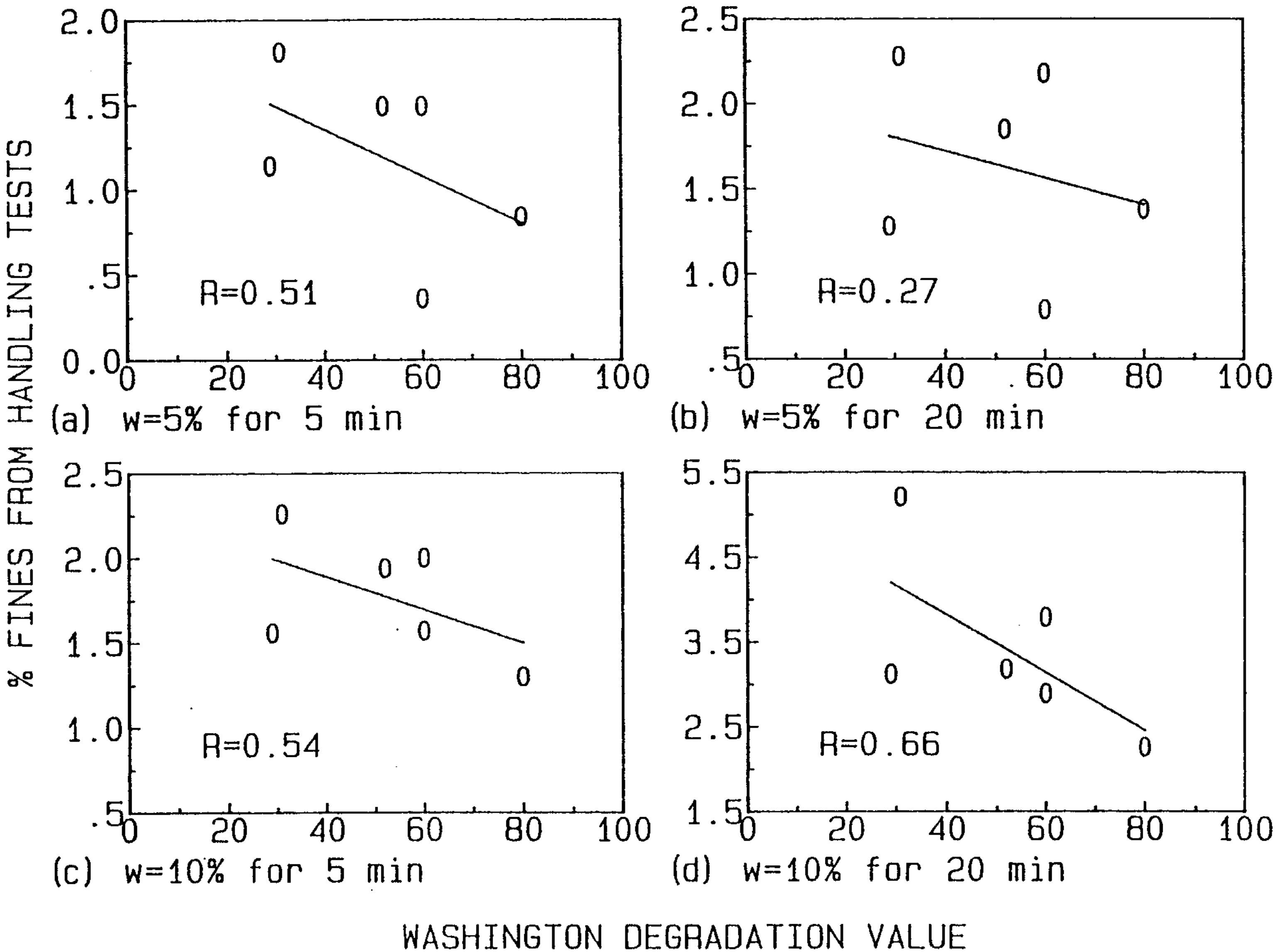


FIGURE 2.5. -- FINES PRODUCED FROM HANDLING TESTS VERSUS WASHINGTON DEGRADATION VALUE.

Figure 2.6 presents the correlations between the fines produced in the compaction tests and the degradation value. The correlations are quite poor. As with the crushing test, the mechanism of fines production, and the method of fines measurement in the compaction tests are different than in the degradation test.

2.9 RECOMMENDED TEST PROCEDURE

The actual amount of fines that are produced in the field during crushing, handling, and placement of roadway aggregates will depend on many factors in addition to lithology. The type of crusher used, the amount of handling that occurs, and the type of compaction equipment used for placement will vary from job to job. To employ the previously described test procedure to accurately predict the amount of fines that will be produced for a given construction history, it would be necessary to correlate the laboratory test results to a large body of well documented field data. At this time, this body of data is not available. Therefore, the test procedure can only be used to indicate the maximum amount of fines that is likely to be produced in the field. To accomplish this, the three part series tests that produces the greatest amount of fines should be adopted. This includes the crushing test, employing 10 to 19 mm (00.38 to 0.75 in.) material, the handling test performed at 10 percent moisture content for 20 minutes, and the Modified AASHTO Compaction Test. The sum of the fines produced following this recommendation is given for six aggregate sources in Table 2.7. The minimum value is 6.5 percent, the maximum is 13.1 percent. All of the sources exceed the 6 percent maximum for roadway aggregates noted in the ADOT&PF specifications.

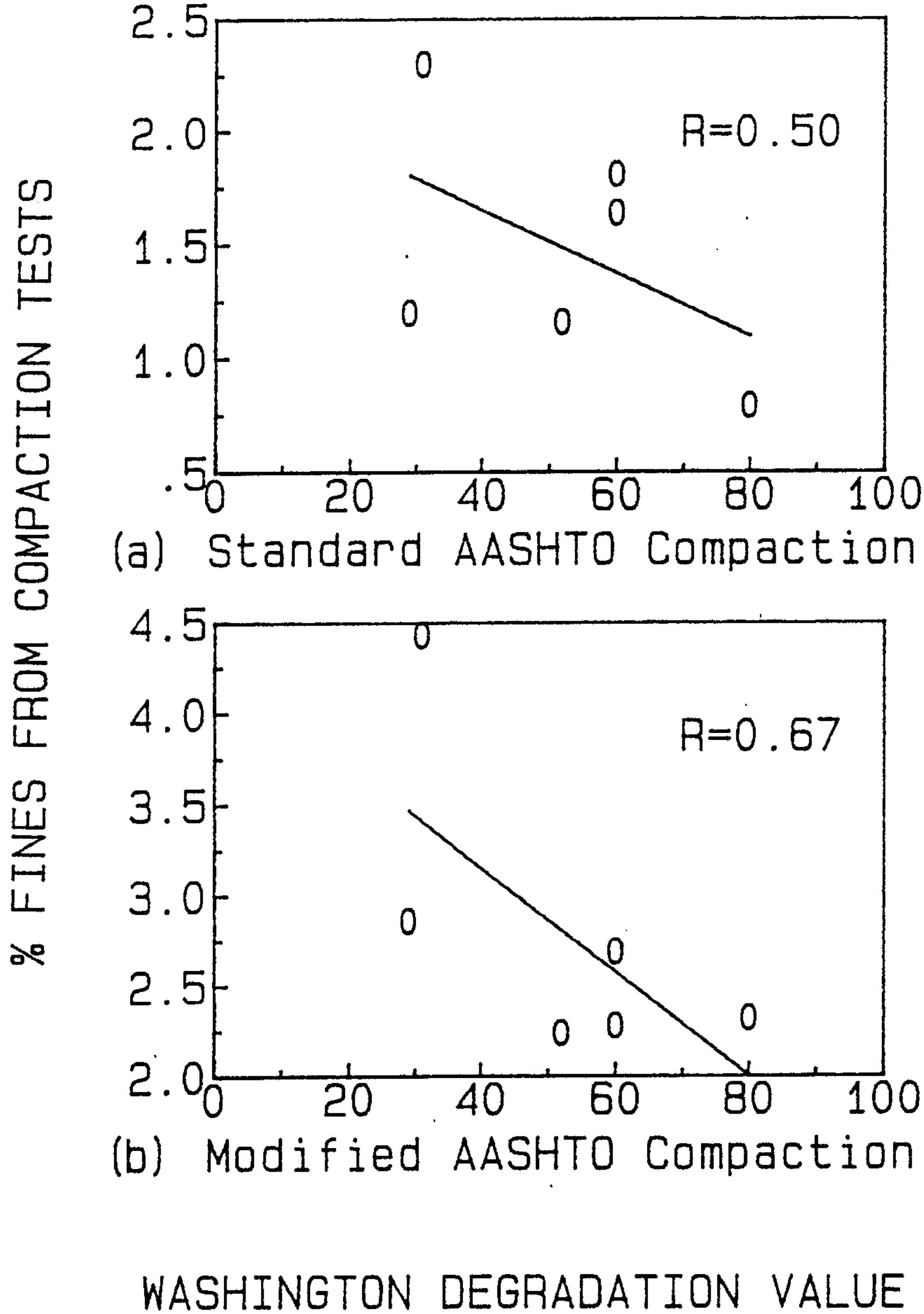


FIGURE 2.6. -- FINES PRODUCED FROM COMPACTION TESTS VERSUS WASHINGTON DEGRADATION VALUE.

Table 2.7 Sum of Fines Produced From Crushing, Handling, and Placement Tests

Source Number and/or Name	Percent Fines
371-001-2, MP J315.5 Parks Hwy.	8.2
21-2-399-1, MP 62.9 Sterling Hwy.	6.5
680-111-2, Chatanika River	7.0
71-1-030-5, MP 47.7, Richardson Hwy.	13.1
Taylor South	6.8
Brown's Hill	8.3

2.10 CONCLUSIONS

Based on the information gained from the development and results of tests that simulate crushing, handling, and placement of roadway aggregates, the following conclusions are appropriate:

1) Specification gradation material cannot be easily produced with a small laboratory jaw crusher without recombining the size fractions produced.
2) In addition to lithology, the quantity of fines produced during crushing depends on the gradation of the feed material.
3) The quantity of fines produced during handling is highly dependent on the moisture content of the aggregate.
4) The Washington degradation test cannot be used as an indicator of the fines production potential of aggregates during crushing, handling, or placement.
5) A three part procedure consisting of the crushing test, the handling test performed at 10 percent moisture content for 20 minutes, and the Modified AASHTO Compaction Test should be used to indicate the maximum amount of fines that is likely to be produced during crushing, handling, and placement of roadway aggregates.

2.11 ACKNOWLEDGEMENTS

This work was funded by the Alaska Department of Transportation and Public Facilities under contract number 85NX167. Their support is gratefully acknowledged. The authors would also like to thank John Heinicke of Oregon State University for his help with the preliminary laboratory investigation.

2.12 REFERENCES

1. Slater, W.H., "Preliminary Report on The Quality of The Material Present in M.S. 71-1-030-5," Alaska Department of Transportation and Public Facilities, Project No. F-071-1(18), November 28, 1977.

2. Aughenbaugh, N.B., Johnson, R.B., and Yoder, E.J., "Degradation of Base Course Aggregates During Compaction," United States Army Cold Regions Research and Engineering Laboratory, Technical Report 166, July 1966.

3. Hoover, J.M., Kumar, S., and Best, T.W., "Degradation Control of Crushed Stone Base Course Mixes During Laboratory Compaction," Highway Research Record, No. 301, Highway Research Board, 1970.

4. Szymoniak, T., "Reliability of the Dimethyl Sulfoxide (DMSO) Accelerated Weathering Test to Predict the Degradation Characteristics of Basaltic Road Aggregates," thesis presented to Oregon State University, Corvallis, Oregon, in 1986, in partial fulfillment of the requirements for the degree of Master of Science.

5. Goldbeck, A.T., Gray, J.E., and Ludlow, L.L., Jr., "A Laboratory Service Test for Pavement Materials," Proceedings of the American Society for Testing and Materials, Vol. 34, Part II, 1934.

6. Tremper, B., "A Test for the Resistance of Stone to Breakage During Rolling," Bulletin 17, State of Washington, Department of Highways, 1935.

7. Rothgery, L.J., "Los Angeles Rattler Test," Rock Products, Vol. 39, no. 12, 1936.

8. Lund, J.W., "Aggregate Degradation Test Evaluation for Road Surfacing Material," Oregon Institute of Technology, August 1976, Klamath Falls, Oregon.

9. West, T.R., Johnson, R.B., and Smith, N.M., "Tests for Evaluating Degradation of Base Course Aggregates," National Cooperative Highway Research Program, Report 98, Highway Research Board, 1970.

10. Rhodes, R., and Mielenz, R.C., "Petrographic and Mineralogic Characteristics of Aggregates," Special Technical Publication No. 83, American Society for Testing and Materials, 1948.

11. Mielenz, R.C., "Petrographic Examination of Concrete Aggregate," Proceedings of the American Society for Testing and Materials, Vol. 54, p. 1188-1218, 1954.

12. De Puy, G.W., "Petrographic Investigations of Rock Durability and Comparisons of Various Test Procedures," Journal of the American Association of Engineering Geologists, Vol. 2, p. 31-46, 1965.

13. Hartely, A., "A Review of the Factors Influencing the Mechanical Properties of Road Surface Aggregates," Quarterly Journal of Engineering Geology, Vol. 7, p. 96-100, 1974.

14. Van Atta, R.D., and Ludowise, H., "Microscopic and X-Ray Examination of Rock for Durability." Report No. FHWARD-77-36, Federal Highway Administration, December, 1976.

15. Cole, W.F., and Sandy, M.J., "A Proposed Secondary Mineral Rating for Basalt Aggregate Durability," Australian Road Research, Vol. 10, No. 3, p. 27-37, September 1980.

16. Lowrison, G.C., Crushing and Grinding: The Size Reduction of Solid Materials, Butterworths, 1974.

3.0 NATURE OF FINES PRODUCED IN AGGREGATE PROCESSING

by

Robert M. Pintner[1], Ted S. Vinson[2], and Eric G. Johnson[3]

ABSTRACT: The fines produced in a three part laboratory test series developed to simulate crushing, handling, and placement of roadway aggregates were compared to fines determined from field records for six aggregate sources in Alaska. These sources were associated with projects experiencing final fines contents in the roadway structure which exceeded that allowed by the State of Alaska. A comparison of the laboratory and field results indicates that the test series may overestimate the quantity of fines that is likely to be produced under normal field conditions. The nature and quantity of fines created in the laboratory test series were analyzed in order to determine their contribution to the frost action susceptibility of a representative base course aggregate. The fines produced are predominately in the coarse silt (0.02 to 0.074 mm) size range. Current frost action susceptibility theories suggest that these fines alone should not render the base course aggregate frost susceptible, but fines present before crushing in combination with those produced in processing may prove to be detrimental to roadway structure performance.

1 Staff Engineer, San Diego Soils Engineering, Inc., San Diego, California 92111, formerly, Graduate Research Assistant, Oregon State University, Corvallis, Oregon 97331.

2 Professor of Civil Engineering, Oregon State University, Corvallis, Oregon 97331.

2 Professor of Civil Engineering, Oregon State University, Corvallis, Oregon 97331.

3 Geotechnical Engineer, Alaska Department of Transportation and Public Facilities, Anchorage, Alaska 99502.

3.1 INTRODUCTION

Engineers in cold regions have long recognized that fines (material passing the No. 200 (0.074 mm) sieve) are produced during crushing, handling, and placement of roadway aggregates. In some instances aggregate sources which have been found to be suitable based on standard mechanical degradation tests (e.g. Los Angeles Abrasion, Washington Degradation, etc.) have experienced substantial fines production during crushing, handling, and placement. This, in turn, has resulted in pavement failures associated with frost heave and thaw weakening in the field or costly redesign of the pavement structure if the increase in fines content is recognized in advance.

While the problem of fines production during processing of roadway aggregates is recognized, little information exists on the quantity and nature of the fines produced. To correct this situation, a laboratory research study was undertaken with the following objectives: (1) determine the quantity of fines produced during crushing, handling, and placement of roadway aggregates; (2) establish the geotechnical characteristics of the fines produced, and implications with respect to frost action potential in roadway aggregates. The scope of the study is limited to evaluation of the fines produced from six aggregate sources. These sources included granitic rocks, schist, quartzite, phyllites, and metamorphosed greywacke, but do not represent all possible rock types. Further, a limited amount of field data regarding the quantity of fines produced during crushing, handling, and placement of six aggregate sources was examined.

An appreciation of the results presented herein is enhanced by a background on previous work to determine the fines produced during the processing of roadway aggregates, and frost action classification systems that relate to the geotechnical characteristics of fines in roadway aggregates. This background is presented in the following sections.

3.2 PRODUCTION OF FINES DURING AGGREGATE PROCESSING

No detailed study has been conducted to evaluate the production of fines which occurs during the crushing and handling processes. In an unpublished preliminary study, Slater (1977) examined the quality of an aggregate source in Alaska. The rock consisted of phyllites and slightly metamorphosed greywacke. When crushed in a laboratory crusher a maximum increase in fines of only 2 percent was noted. Slater concluded from this that the aggregate does not produce significant amounts of fines during crushing. To simulate handling, the aggregate was shaken in a stainless steel container with a Tyler sieve shaker for five minutes. Only insignificant amounts of fines were produced when the aggregate was tested in a dry state. However, when tested at 5 percent moisture content, as much as 5 percent fines were produced. Slater concluded that significant quantities of fines were likely to be produced during handling of this aggregate. As a control, a durable aggregate (Tanana River gravel) was tested in the same manner. At 5 percent moisture content a maximum of 0.8 percent fines was produced.

Aughenbaugh et al. (1966) considered a glacial gravel (containing a variety of rock types) in their study to evaluate the degradation that occurs during the placement and compaction of a base course. Field tests were performed with three types of compaction equipment: steel-wheel roller, vibratory roller, and pneumatic rubber-tired. A direct relationship was observed between the amount of degradation and the initial grading of an aggregate. Uniform gradings experienced more general breakdown than dense gradings, but no significant difference in the amount of fines produced was observed. Most degradation occurred in the top of the lift during the first compaction pass, and decreased with each subsequent pass. After evaluating several laboratory tests, including the Los Angeles Abrasion, mechanical kneading compactor, repetitive loading, modified AASHTO, freeze-thaw, and absorption and specific gravity, Aughenbaugh et al. concluded that there is no single physical test or combination of tests that may be used to evaluate production of fines for all aggregate types and construction histories. Of all the tests evaluated, only the Los Angeles Abrasion test showed promise of being useful.

Hoover et al. (1970) also studied the degradation of base course aggregates subjected to various types of laboratory compaction. They concluded that at a particular combination of frequency, amplitude, surcharge weight, and duration, vibratory compaction produced little or no visible breakdown. Other methods, including standard and modified AASHTO compaction, static compaction, and drop hammer compaction (i.e., molding an entire, non-layered specimen by drop hammering on both the top and bottom), produced significant degradation in aggregates having good service records. The rock for this study consisted of two limestone sources, and one dolomite source.

Szymoniak (1986) employed repeated load cyclic triaxial tests to determine the production of fines associated with traffic loadings of base course basaltic aggregates. The fines content increased on average from an initial value of 1.6 percent to a final value of 2.5 percent after 100,000 cycles of loading. The results indicate that traffic loading does not produce substantial increases in fines for basalt aggregates.

3.3 FROST ACTION CLASSIFICATION SYSTEMS

Frost action is defined as the process of frost heave, and associated thaw weakening. The majority of the research work related to frost action is concerned with frost heave only.

Chamberlain (1981) reviewed frost susceptibility index tests and classification systems. He examined over 100 classification systems. Classification systems based on grain size characteristics were found to be the most popular because of their simplicity. The systems that involve pore size, soil-water interaction, or soil-ice interaction may be more closely related to the actual mechanism of frost heave, but none of these systems are universally applicable. In addition they are more difficult to use.

The majority of the classification systems that employ grain size are based on a percentage of material passing the No. 200 sieve. However, there is little agreement on the quantity of fines necessary to render the soil susceptible to frost action. The allowable fines content ranges from 6 percent (Alaska) to 35 percent (Delaware). The second most common grain size used for classification is 0.02 mm. The best known, and probably the most widely employed classification system is based on the Casagrande Criteria. The criteria states that nonuniform soils having more than 3 percent finer than 0.02 mm and uniform soils having more than 10 percent finer than 0.02 mm will be frost susceptible. Nonuniform soils having between 1 and 3 percent finer than 0.02 mm and, uniform soils having between 1 and 10 percent finer than 0.02 mm will be little frost susceptible. All soils having less than 1 percent finer than 0.02 mm will be non-frost susceptible (Casagrande, 1931). A few classification systems employ other grain sizes, but most of these fall within the range of 0.02 to 0.074 mm or slightly larger. Chamberlain concluded, in general, that the 0.02 mm grain size is more reliable than the 0.074 mm size to identify susceptibility to frost action, but as of yet no single test adequately classifies the frost susceptibility of soils.

Rieke et al. (1983) noted that the mechanism of frost heave is fundamentally related to the specific surface area of the soil, which in turn can be related to index property test results. They conducted a series of laboratory frost heave tests on soil mixtures with known index properties, and interpreted the results through the concept of segregation potential (Konrad and Morgenstern, 1980). The measured segregation potentials, when related to geotechnical characteristics of the soil mixtures led to the development of the fines factor. The fines factor is defined as follows:

$$R_f = \frac{(\%\ \text{fines})(\%\ \text{clay size in fines fraction})}{LL_{ff}} \qquad (3.1)$$

in which: R_f = fines factor

LL_{ff} = liquid limit of the fines fraction

The fines factor was found to be directly related to the segregation potential.

Vinson et al. (1985), employing frost heave test results from forty-four tests on mixtures of coarse-grained soils with a fine fraction of silt and clay, compared heave rate and segregation potential to: (1) percent particles finer than 0.074 mm; (2) percent particles finer than 0.02 mm; and (3) fines factor. The correlations established were not strong for the 0.074 mm size (R^2 = 0.47), good for the 0.02 mm size (R^2 = 0.72), and very strong for the fines factor (R^2 = 0.92). Based on the results of their study they concluded that factors in addition to grain size must be considered in the development of frost heave susceptibility criteria for coarse grained soils.

McHattie et al. (1980) related roadway performance to material properties including: (1) percent passing the No. 200 sieve; (2) percent finer than 0.02 mm; (3) the Corps of Engineers Frost Susceptibility Classification Value (FSV); and (4) heave rates from laboratory tests. Pavement performance was characterized by percent area of alligator cracking, wheel rut depth, and peak spring thaw deflections. A good correlation was established between pavement performance and the percentage of 0.02 mm material in the base course. However, a stronger correlation was established between field performance and percent fines. When correlated with heave rates from laboratory tests, the percentage of 0.02 mm material showed a stronger correlation than the percentage of fines. Heave rates correlated with field performance in a general way only. Material which showed heave rates greater than 3 mm per day generally corresponded with poor pavement performance. Heave rates of less than 3 mm per day corresponded with good performance. The FSV classification had a poor correlation with field performance. As a result of this work, the Alaska Department of Transportation and Public Facilities (ADOT&PF) changed their aggregate specifications. At the present time only 6 percent fines are allowed in the base course. This implies that very strict control of fines must be maintained during roadway construction.

3.4 FIELD OBSERVATIONS AND LABORATORY TEST PROCEDURES

The quantity of fines produced during crushing, handling, and placement can be established through field studies and laboratory testing. Field data was obtained for several aggregate sources in Alaska. Ideally the field data would include the following: (1) percent fines before crushing; (2) percent fines after crushing; (3) percent fines before compaction; and (4) percent fines after compaction. The percent fines before crushing was not available for the sources considered. For all of the field samples, it was possible to obtain the percent fines off the crusher and after compaction. In some cases data was obtained from the stockpile or the windrow. The data available for the aggregate sources also includes Washington Degradation Test values for all sources, including those sampled for laboratory testing.

A laboratory test procedure for predicting the likely maximum fines content associated with crushing, handling, and placement of aggregates has been described by Pintner, et al. (1986). The procedure consists of a series of separate tests which simulate field processing of aggregates. Initially, a representative bulk sample of aggregate source material is obtained and thoroughly washed. The crushing test consists of processing a 3000 gm (6.62 lbs) sample of clean 10 to 19 mm (0.38 to 0.75 in.) material through a small laboratory jaw crusher. In the handling test, a 1000 gm (2.21 lbs) sample of clean, moist, well-graded material is agitated in a 38 cm^3 (1 gal.), 21 cm (8.25 in.) diameter, stainless-steel container with a sieve shaker. The test is performed on aggregates at a moisture content of 10 percent, agitated for 20 minutes. Field compaction is simulated with the modified AASHTO compaction test (ASTM D698-70). The material is compacted at 5 percent moisture content. A brief description of the field and laboratory samples is given in Table 3.1. All of the samples were provided by ADOT&PF. They were taken from various material sources in Alaska which have in the past exhibited poor or marginal performance.

The fines produced from each phase of testing were saved and combined to create a sample representing the fines produced during the entire construction process. A hydrometer analysis (ASTM D421) was performed on each sample in

Table 3.1 Aggregate Source Descriptions

Source Number and/or Name	Rock Type	Fines Production	
		Lab Data Available	Field Data Available
(1)	(2)	(3)	(4)
371-001-2, MP 315.5 Parks Hwy.	Schist and Quartzite	X	X
21-2-399-1, MP 62.9 Sterling Hwy.	Metagreywacke	X	X
680-111-2, Chatanika River	Schist and Quartzite	X	
71-1-030-5, MP 47.7 Richardson Hwy.	Phyllite and Metagreywacke	X	X
Taylor South	Granitic	X	
Brown's Hill	Basalt	X	
371-156-2, MP 317.5 Parks Hwy.	Schist and Quartzite		X
680-094-2, MP 6 Elliott Hwy.	Schist and Quartzite		X
621-007-5, Paradise Hills	Amphibolite		X

order to determine the gradation of the fines produced. To calculate the fines factor, the liquid limit (ASTM 4318) of the fines was determined.

3.5 FIELD AND LABORATORY TEST RESULTS

In order to directly compare the laboratory and field results of an aggregate source, it is essential that the sample taken for laboratory testing be representative of the material used in the field. Much of the field data for this study is from construction projects that were completed as early as 1977. Since that time, many of the quarries have been discontinued as sources for roadway aggregates. All of the samples for the laboratory study were obtained in the spring of 1985. Therefore, it is possible that the samples are not entirely representative of the material previously used. Washington Degradation Test values for the field material, and the laboratory samples are shown in Figure 3.1. The sources which show fairly close agreement may, in fact, indicate equivalent samples, while the others indicate non-equivalent samples.

The fines produced in the field and in the laboratory test series are shown in Figure 3.2 (note that the field and laboratory sources are not necessarily the same). In general, more fines are produced in the laboratory handling and placement tests than in the field. This suggests that the laboratory tests are excessively harsh, but a definitive conclusion cannot be made based on the limited field data. The fact that the quantity of fines after crushing in the field is, in general, twice as great as that produced in the laboratory indicates that material crushed in the field contained an appreciable amount of fines before crushing. The substantial difference in the fines produced in the field may possibly be attributed to differences in lithology, type of compaction equipment, or both.

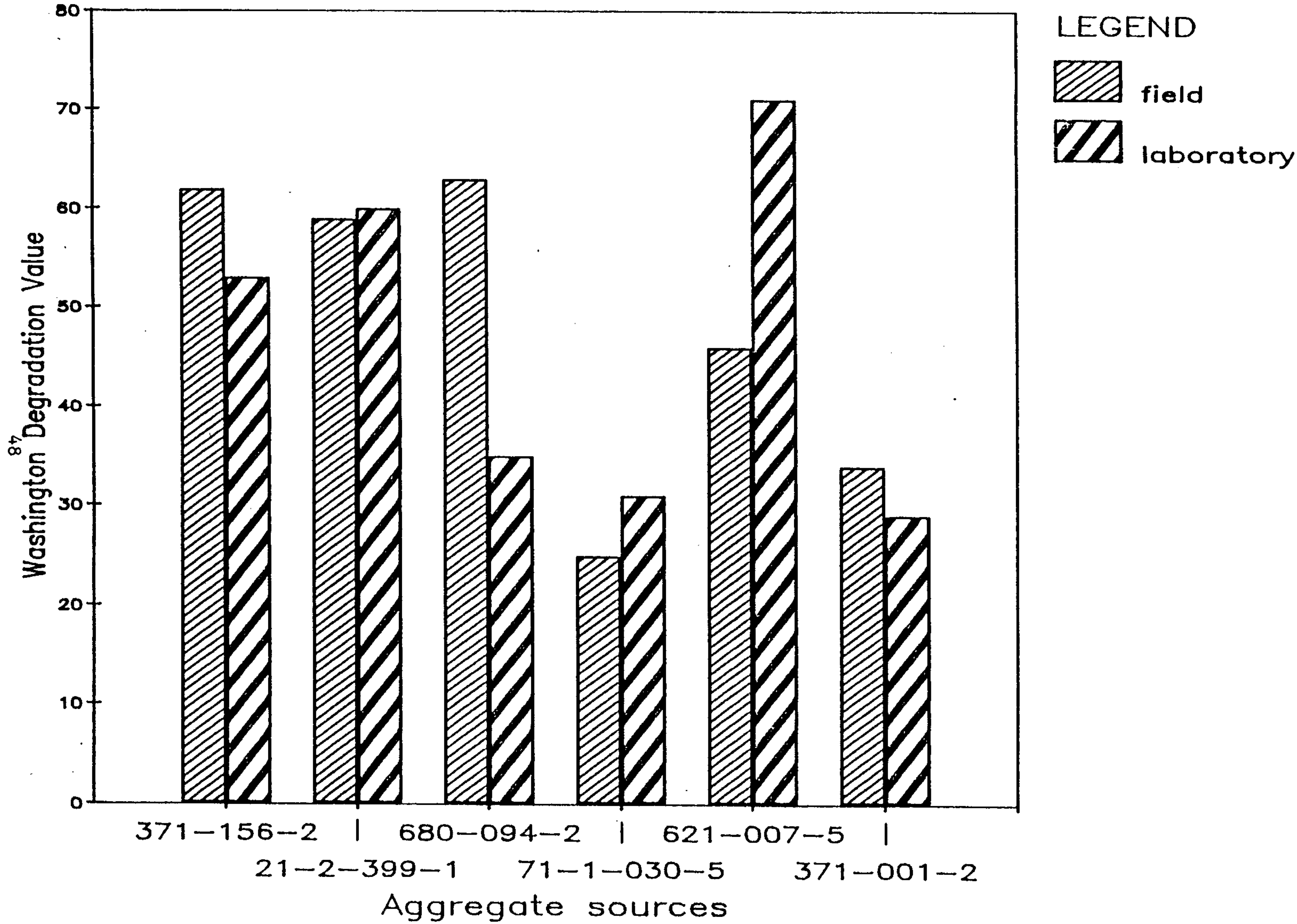
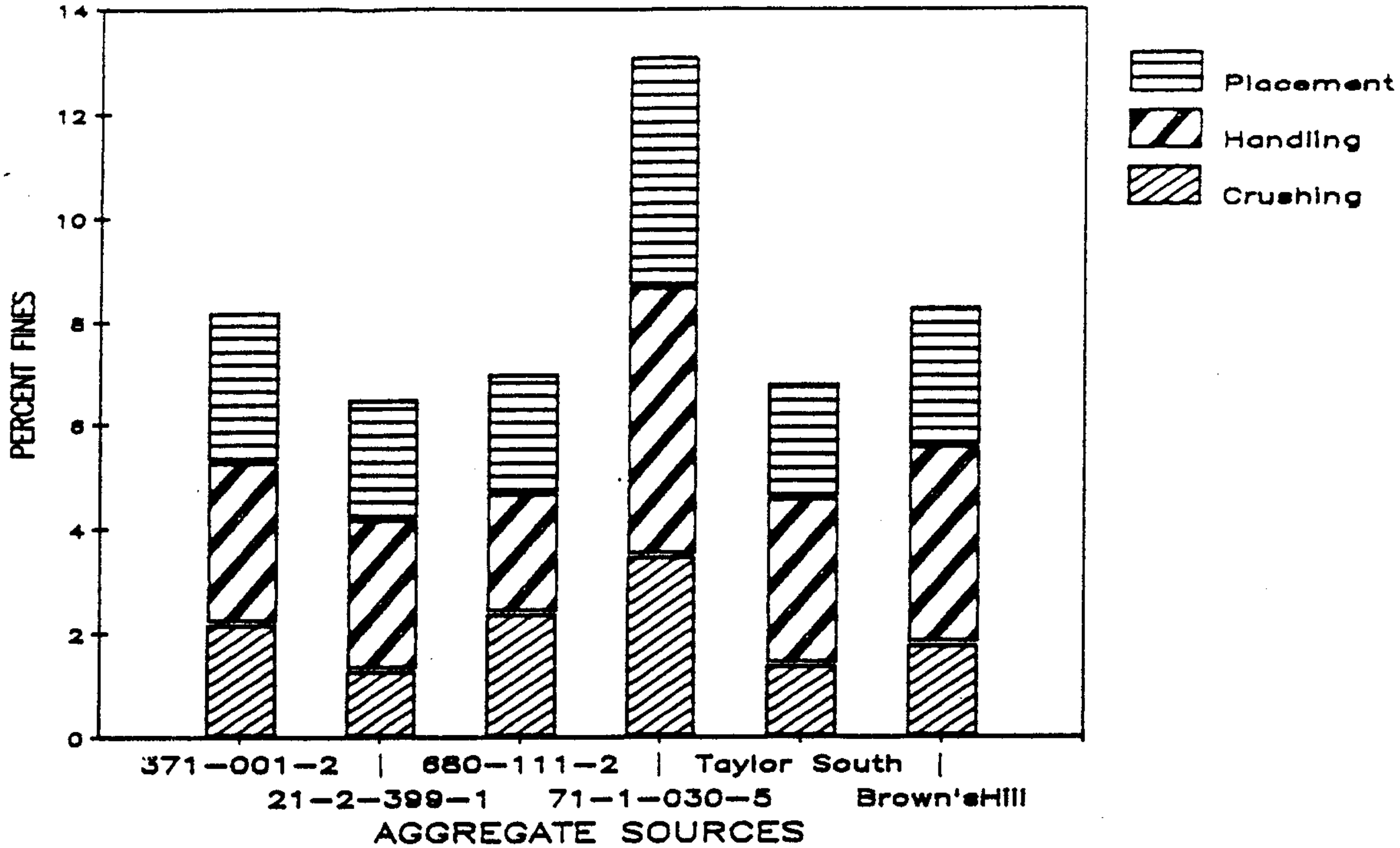


FIGURE 3.1. -- COMPARISON OF WASHINGTON DEGRADATION VALUES FROM THE LABORATORY AND FIELD.

a) Percent Fines From Laboratory Tests.



b) Percent Fines From Field.

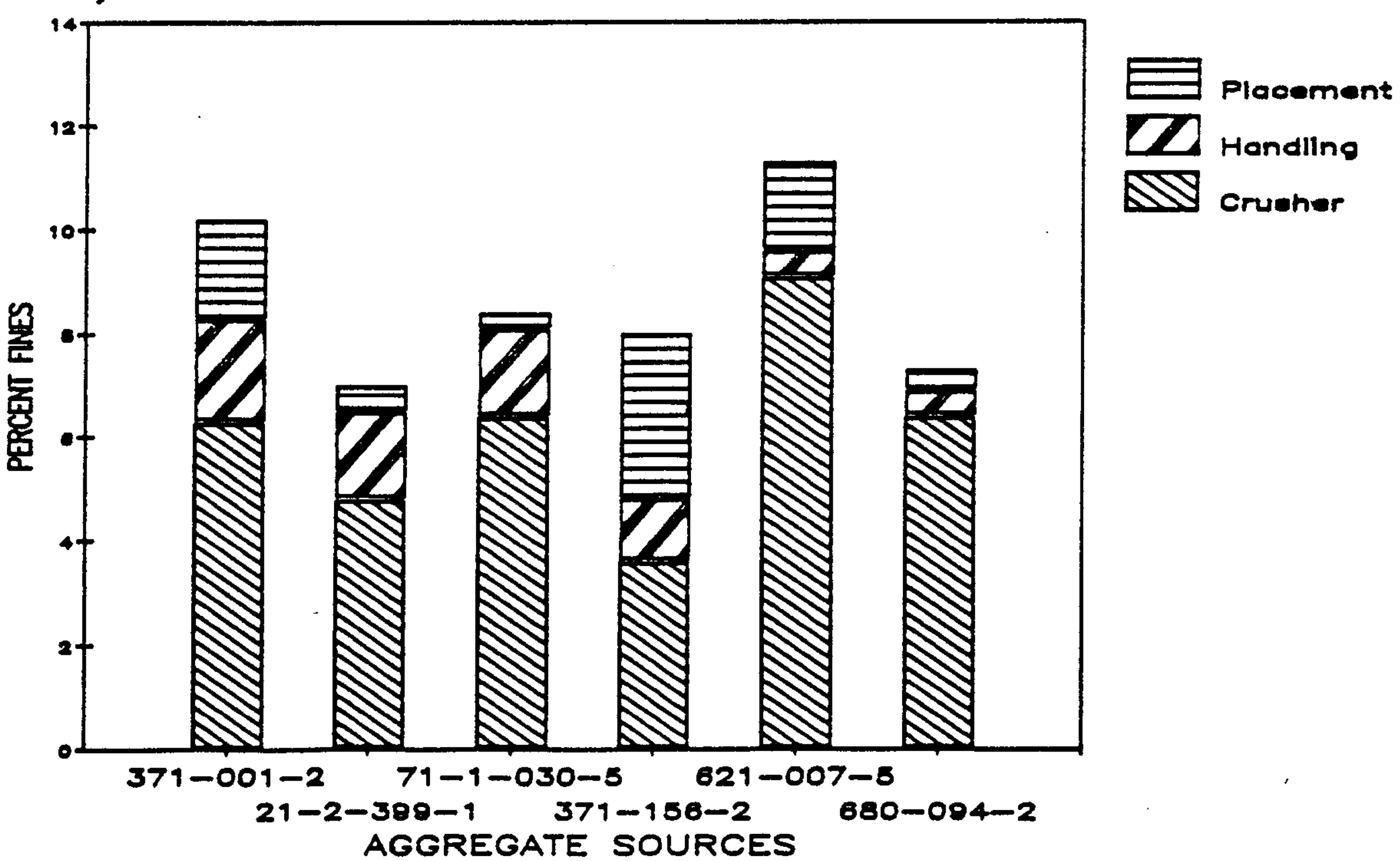


FIGURE 3.2 -- FINES PRODUCED FROM CRUSHING, HANDLING, AND PLACEMENT.

Geotechnical characteristics of the fines produced in the laboratory crushing, handling, and placement test series are given in Table 3.2, and shown in Figure 3.3 The fines produced are mostly in the range of coarse silt (0.074 to 0.02 mm). Only two out of the six samples contained more than 20 percent finer than 0.02 mm, with 34 percent being the maximum. All of the samples contained less than 9 percent clay size (<0.002 mm), with only one containing greater than 2 percent. The liquid limits ranged from 21 to 34.

3.6 DISCUSSION OF FROST ACTION SUSCEPTIBILITY

The entire gradation of a soil is needed to give an indication of its susceptibility to frost action. In this regard, a hypothetical base course aggregate was generated, following the ADOT&PF specification for base course aggregates. The aggregate was assumed to be initially free of any fines. Next, the amount of fines determined by the crushing, handling, and placement laboratory tests series was added to the original gradation. Based on the resulting percentage of material finer than 0.074 and 0.02 mm, each hypothetical base course was classified according to Casagrande's Criteria, and the ADOT&PF specification for base course aggregates; based on the percent clay size in the fines fraction and the liquid limit of the fines fraction, the hypothetical base courses were assigned a fines factor (re. equation 3.1).

The range of possible gradations of the initially clean aggregate is shown in Figure 3.4. Aggregates of this gradation classify as GW or SW (depending on the percent passing the No. 4 sieve) under the Unified Soil Classification System (USCS). With the added fines, five of the samples classify as GW/GM or SW/SM, and one classifies as GM or SM, as noted in Table 3.3 together with other geotechnical characteristics of the hypothetical base course aggregates.

Table 3.2 Geotechnical Characteristics of the Fines Produced During Crushing, Handling, and Placement Laboratory Test Series

Source Number and/or Name (1)	Percent in Fines Fraction <0.02 mm (2)	Percent in Fines Fraction <0.002 mm (3)	Liquid Limit of Fines Fraction (4)
371-001-2, MP 315.5 Parks Hwy.	4.6	1.5	31
21-2-399-1, MP 62.9 Sterling Hwy.	34.4	8.6	21
680-111-2, Chatanika River	4.2	1.1	34
71-1-030-5, MP 47.7 Richardson Hwy.	10.3	0.8	30
Taylor South	24.5	1.6	27
Brown's Hill	5.3	1.6	30

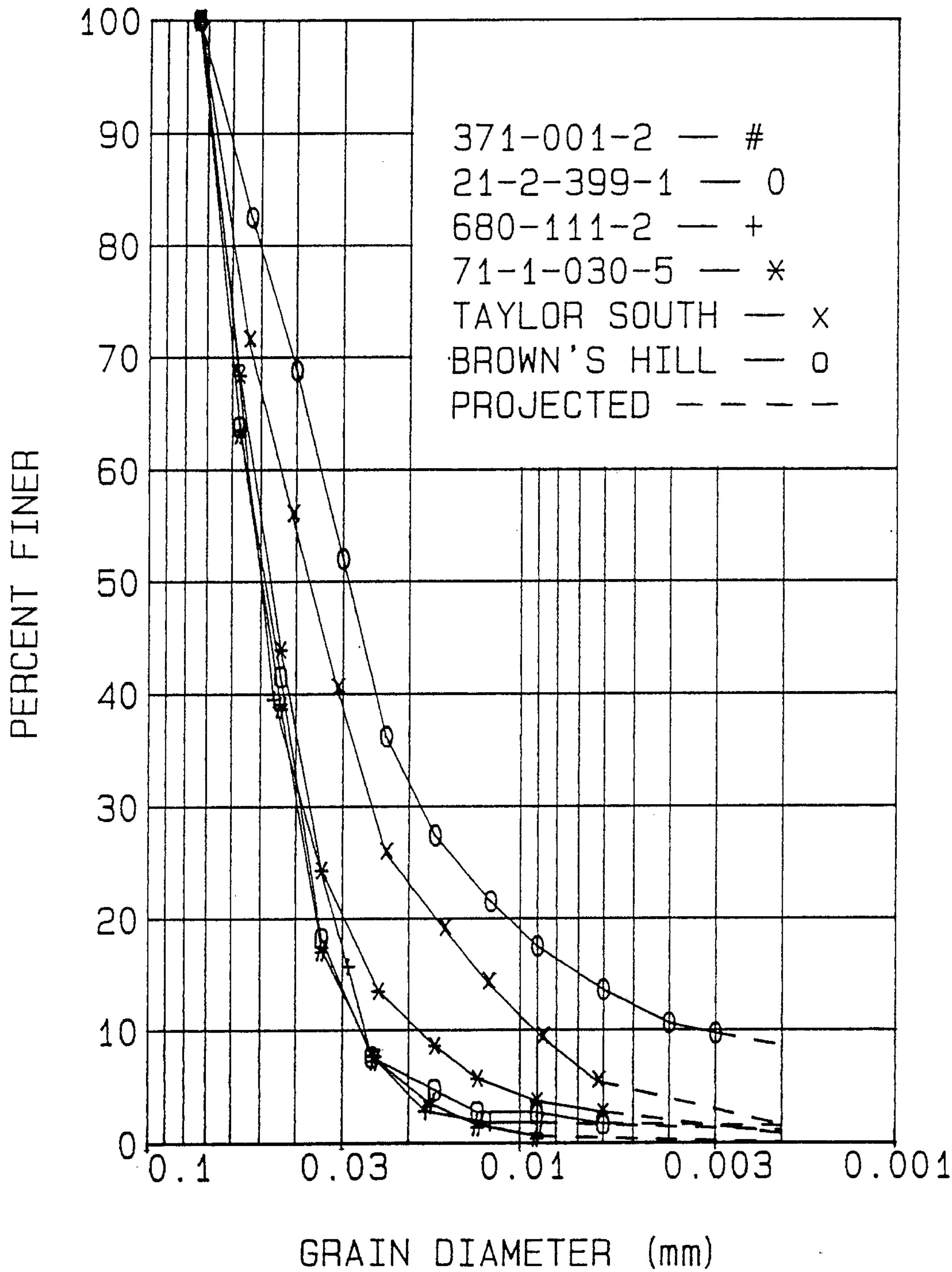


FIGURE 3.3. -- GRADATION OF FINES PRODUCED IN THE LABORATORY TEST SERIES.

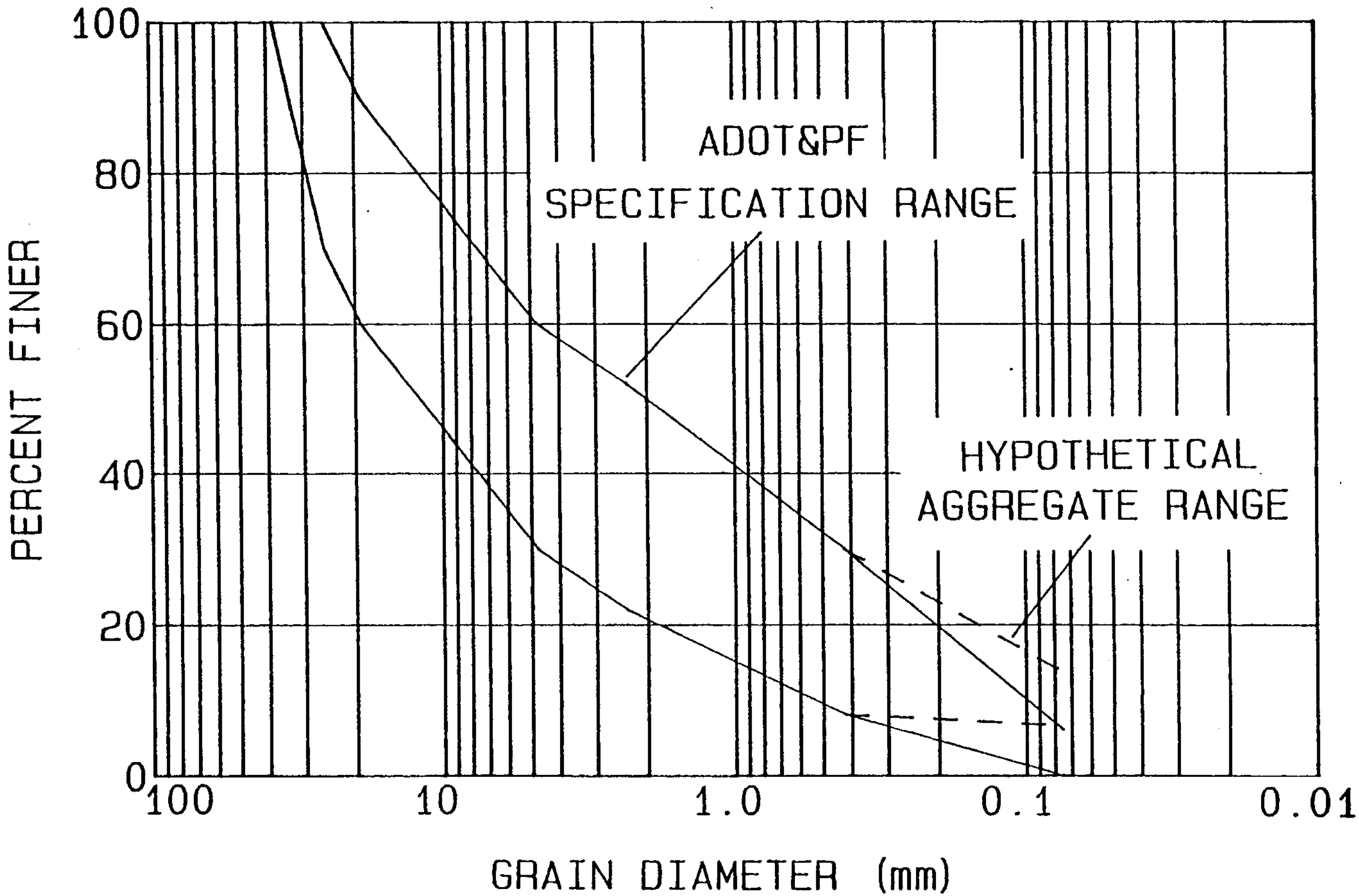


FIGURE 3.4. -- ADOT&PF SPECIFICATION AND HYPOTHETICAL BASE COURSE AGGREGATE GRADATION RANGE.

Table 3.3 Character of Hypothetical Base Course Aggregates

Source Number and/or Name (1)	USCS Classification (2)	Percent Fines (3)	Percent <0.02 mm (4)	Percent <0.002 mm (5)	Casagrande Classification (6)	Fines Factor (7)
371-001-2, MP 315.5 Parks Hwy.	SW/SM, GW/GM	8.2	0.4	0.1	NFS	0.4
21-2-399-1, MP 62.9 Sterling Hwy.	SW/SM, GW/GM	6.5	2.2	0.6	LFS	2.7
680-111-2, Chatanika River	SW/SM, GW/GM	7.0	0.3	0.1	NFS	0.2
71-1-030-5, MP 47.7 Richardson Hwy.	SM, GM	13.1	1.4	0.1	LFS	0.3
Taylor South	SW/SM, GW/GM	6.8	1.7	0.1	LFS	0.4
Brown's Hill	SW/SM, GW/GM	8.3	0.4	0.1	NFS	0.4

According to Casagrande's Criteria, none of the soils can be classified as frost susceptible, three can be classified as little-frost susceptible, and three as non-frost susceptible. Based on the ADOT&PF specification of 6 percent passing the No. 200 sieve, none of the samples are acceptable.

The fines factors of the hypothetical aggregates are very low. Source 21-2-399-1 has a fines factor of 2.7. The other sources have fines factors less than one. Rieke et al. (1985) indicate that fines factors in this range are associated with laboratory heave rates of less than 1 mm/day in a constant boundary temperature frost heave test. The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) provide a frost heave classification system based on heave rates in a constant rate penetration frost heave test (Kaplar 1974). Ahmad (1983) analyzed the two types of frost heave tests and found that at near steady state conditions, the heave rates in the constant boundary temperature test were greater by about 1 mm/day than in the constant rate of penetration test. As a result of his analysis Ahmad proposed a modification to the CRREL frost heave classification system that would allow it to employed with heave rates determined in the constant boundary temperature test. The modified classification system indicates that soils having laboratory heave rates of less than 1.5 mm/day have negligible susceptibility to frost heave. McHattie et al. (1980) noted that material with laboratory heave rates of less than 3 mm/day in a constant rate of penetration test were generally associated with good pavement performance. This would be equivalent to approximately 4 mm/day in a constant boundary temperature test. Consequently the fines factor data supports, in addition to the Casagrande Criteria, the assertion that the hypothetical aggregates are not susceptible to frost heave.

While the fines produced during crushing, handling, and placement apparently do not render an initially clean aggregate susceptible to frost action, an aggregate having some initial fines content may be so effected. All of the hypothetical aggregates in this study were initially clean. The field data indicates that the material sources generally have an appreciable fines content. These fines are the result of weathering in the case of a bedrock source, or were deposited with the coarser material in the case of an alluvial deposit. In either case an appreciable amount of fine silt or clay may be present which, when combined with the fines produced during crushing, handling, and placement, may render the aggregate unacceptable.

3.7 CONCLUSIONS

Considering information presented herein the following conclusions are appropriate:

1) No single aspect of aggregate processing (i.e. crushing, handling, and placement) dominates fines production.

2) The handling, and placement segments of the the three part test series developed to simulate fines production during processing may be too harsh. It must be emphasized that this conclusion is based on a comparison of laboratory test results and field records, and should be further substantiated as additional field data becomes available.

3) The fines produced during crushing, handling, and placement of initially clean aggregates are primarily non-plastic, coarse silts containing very little clay size material.

4) According to current frost action susceptibility theory, the fines produced during crushing, handling, and placement of

initially clean roadway aggregates will not render the material susceptible to frost action.

5) The initial fines content of the material in combination with the fines produced during aggregate processing may result in base course that is susceptible to frost action.

3.8 ACKNOWLEDGEMENTS

This work was funded by the Alaska Department of Transportation and Public Facilities under contract number 85NX167. Their support is gratefully acknowledged.

3.9 REFERENCES

1. Ahmad, F., "Role of the fines Content in the Frost Heave Susceptibility of Coarse-Grained Soils," engineering report presented to Oregon State University, Corvallis, Oregon, in 1983, in partial fulfillment of the requirements for the degree of Master of Science.

2. Aughenbaugh, N.B., Johnson, R.B., and Yoder, E.J., "Degradation of Base Course Aggregates During Compaction," United States Army Cold Regions Research and Engineering Laboratory, Technical Report 166, July 1966.

3. Casagrande, A., "Discussion of Frost Heaving," Highway Research Board, Proceedings, Vol. 11, p. 168-172, 1931.

4. Chamberlain, E.J., "Frost Susceptibility of Soils, Review of Index Tests," Monograph 81-2, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 1981.

5. Hoover, J.M., Kumar, S., and Best, T.W., "Degradation Control of Crushed Stone Base Course Mixes During Laboratory Compaction," Highway Research Record, No. 301, Highway Research Board, 1970.

6. Kaplar, C.W., "Freezing Test for Evaluating Relative Frost Susceptibility of Various Soils," Technical Report 250, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 1974.

6. Konrad, J.M., and Morgenstern, N.R., "The Segregation Potential of a Freezing Soil," Canadian Geotechnical Journal, Vol. 18, No. 4, p. 482-491, 1981.

7. McHattie, R.L., Connor, B.G., and Esch, D.C., "Pavement Structure Evaluation of Alaskan Highways," Report No. FHWA-AK-RD-81-7, Federal Highway Administration, March, 1980.

8. Pintner, R.M., Vinson, T.S., and Johnson, E.G., "Quantity of Fines Produced During Crushing, Handling, and Placement of Roadway Aggregates," submitted for publication in: Geotechnical Testing Journal, American Society for Testing and Materials, 1986.

9. Rieke, R.D., Vinson, T.S., and Mageau, D.W., "The Role of the Specific Surface Area and Related Index Properties in the Frost Heave Susceptibility of Soils," Proceedings, Fourth International Conference on Permafrost, Fairbanks, Alaska, 1983.

10. Slater, W.H., "Preliminary Report on The Quality of The Material Present in M.S. 71-1-030-5," Alaska Department of Transportation and Public Facilities, Project No. F-071-1(18), November 28, 1977.

11. Szymoniak, T., "Reliability of the Dimethyl Sulfoxide (DMSO) Accelerated Weathering Test to Predict the Degradation Characteristics of Basaltic Road Aggregates," thesis presented to Oregon State University, Corvallis, Oregon, in 1986, in partial fulfillment of the requirements for the degree of Master of Science.

12. Vinson, T.S., Ahmad, F., and Rieke, R.D., "Factors Important to the Development of Frost Heave Susceptibility Criteria For Coarse-Grained Soils," accepted for publication in the <u>Transportation Research Board Record</u>, 1986.

4.0 CONCLUSION

4.1 SUMMARY

A three part test procedure was developed to simulate the production of fines during crushing, handling, and placement of roadway aggregates. Results of the test procedure were correlated to a standard aggregate degradation test (the Washington Degradation Test). Records of the fines produced during crushing, handling, and placement in the field were examined with respect to the laboratory test results. The fines produced in the three part procedure were analyzed to determine their nature with respect to contributing to potential frost action in base course aggregates.

4.2 CONCLUSIONS

Based on the information gained from the development and results of tests that simulate crushing, handling, and placement of roadway aggregates, and from examination of the fines produced, the following conclusions are appropriate:

1) Specification gradation material cannot be easily produced with a small laboratory jaw crusher without recombining the size fractions produced.

2) In addition to lithology, the quantity of fines produced during crushing depends on the gradation of the feed material.

3) The quantity of fines produced during handling is highly dependent on the moisture content of the aggregate, and the duration of agitation.

4) The Washington degradation test cannot be used as an indicator of the fines production potential of aggregates during crushing, handling, or placement.

5) A three part procedure consisting of the crushing test, the handling test performed at 10 percent moisture content for 20 minutes, and the Modified AASHTO Compaction Test should be used to indicate the maximum amount of fines that is likely to be produced during crushing, handling, and placement of roadway aggregates.

6) No single aspect of aggregate processing (i.e. crushing, handling, and placement) dominates fines production.

7) The handling, and placement segments of the three part test series developed to simulate fines production during processing may be too harsh; this conclusion is based on a comparison of laboratory test results and field records, and should be further substantiated as additional field data becomes available.

8) The fines produced during crushing, handling, and placement of aggregates are primarily non-plastic, coarse silts containing very little clay size material.

9) According to current frost action susceptibility classification system the fines produced during crushing, handling, and placement of roadway aggregates will not render an initially clean material susceptible to frost action.

10) The initial fines content of the material in combination with the fines produced during aggregate processing may result in base course that is susceptible to frost action.

4.3 RECOMMENDATIONS

Although valuable results were obtained from the research effort, a number of additional areas of investigation should be considered as follows:

1) A larger variety of rock types should be tested with the suggested procedure. It is especially important that rock with good service records be tested in order to establish the lower limit of fines production of the procedure.

2) A large body of well-documented field data should be obtained for correlation with the three part test procedure.

3) In order to document the frost heave susceptibility of the aggregates considered in Chapter 3, laboratory frost heave tests should be performed on aggregates containing the fines produced in the crushing, handling, and placement simulation tests.

BIBLIOGRAPHY

1. Ahmad, F., "Role of the Fines Content in the Frost Heave Susceptibility of Coarse-Grained Soils," Engineering report presented to Oregon State University, Corvallis, Oregon in 1983, in partial fulfillment of the requirements for the degree of Master of Science.

2. Aughenbaugh, N.B., Johnson, R.B., and Yoder, E.J., "Degradation of Base Course Aggregates During Compaction," United States Army Cold Regions Research and Engineering Laboratory, Technical Report 166, July 1966.

3. Casagrande, A., "Discussion of Frost Heaving," Highway Research Board, Proceedings, Vol. 11, p. 168-172, 1931.

4. Chamberlain, E.J., "Frost Susceptibility of Soils, Review of Index Tests," Monograph 81-2, U.S. Army Cold Region and Research Laboratories, Hanover, New Hampshire, 1981.

5. Cole, W.F., and Sandy, M.J., "A Proposed Secondary Mineral Rating for Basalt Aggregate Durability," Australian Road Research, Vol. 10, No. 3, p. 27-37, September 1980.

6. De Puy, G.W., "Petrographic Investigations of Rock Durability and Comparisons of Various Test Procedures," Journal of the American Association of Engineering Geologists, Vol. 2, p. 31-46, 1965.

7. Goldbeck, A.T., Gray, J.E., and Ludlow, L.L., Jr., "A Laboratory Service Test for Pavement Materials," Proceedings of the American Society for Testing and Materials, Vol. 34, Part II, 1934.

8. Hartely, A., "A Review of the Factors Influencing the Mechanical Properties of Road Surface Aggregates," Quarterly Journal of Engineering Geology, Vol. 7, p. 96-100, 1974.

9. Hoover, J.M., Kumar, S., and Best, T.W., "Degradation Control of Crushed Stone Base Course Mixes During Laboratory Compaction," Highway Research Record, No. 301, Highway Research Board, 1970.

10. Kaplar, C.W., "Freezing Test for Evaluating Relative Frost Susceptibility of Various Soils," Technical Report 250, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 1974.

11. Konrad, J.M., and Morgenstern, N.R., "The Segregation Potential of a Freezing Soil," Canadian Geotechnical Journal, Vol. 18, No. 4, p. 482-491, 1981.

12. Lowrison, G.C., Crushing and Grinding: The Size Reduction of Solid Materials, Butterworths, 1974.

13. Lund, J.W., "Aggregate Degradation Test Evaluation for Road Surfacing Material," Oregon Institute of Technology, August 1976, Klamath Falls, Oregon.

14. McHattie, R.L., Connor, B.G., and Esch, D.C., "Pavement Structure Evaluation of Alaskan Highways," Report No. FHWA-AK-RD-81-7, Federal Highway Administration, March, 1980.

15. Mielenz, R.C., "Petrographic Examination of Concrete Aggregate," Proceedings of the American Society for Testing and Materials, Vol. 54, p. 1188-1218, 1954.

16. Pintner, R.M., Vinson, T.S., and Johnson, E.G., "Quantity of Fines Produced During Crushing, Handling, and Placement of Roadway Aggregates," to be submitted to: Geotechnical Testing Journal, American Society for Testing and Materials, 1986.

17. Rhodes, R., and Mielenz, R.C., "Petrographic and Mineralogic Characteristics of Aggregates," Special Technical Publication No. 83, American Society for Testing and Materials, 1948.

18. Rieke, R.D., Vinson, T.S., and Mageau, D.W., "The Role of the Specific Surface Area and Related Index Properties in the Frost Heave Susceptibility of Soils," Proceedings, Fourth International Conference on Permafrost, Fairbanks, Alaska, 1983.

19. Slater, W.H., "Preliminary Report on The Quality of the Material Present in M.S. 71-1-030-5," Alaska Department of Transportation and Public Facilities, Project No. F-071-1(18), November 28, 1977.

20. Rothgery, L.J., "Los Angeles Rattler Test," Rock Products, Vol. 39, No. 12, 1936.

21. Szymoniak, T., "Reliability of the Dimethyl Sulfoxide (DMSO) Accelerated Weathering Test to Predict the Degradation Characteristics of Basaltic Road Aggregates," thesis submitted to Oregon State University, Corvallis, Oregon, in partial fulfillment of the degree of Master of Science, September 1986.

22. Tremper, B., "A Test for the Resistance of Stone to Breakage During Rolling," Bulletin 17, State of Washington, Department of Highways, 1935.

23. Van Atta, R.D., and Ludowise, H., "Microscopic and X-Ray Examination of Rock for Durability," Report No. FHWARD-77-36, Federal Highway Administration, December 1976.

24. Vinson, T.S., Ahmad, F., and Rieke, R.D., "Factors Important to the Development of Frost Heave Susceptibility Criteria for Coarse-Grained Soils," accepted for publication in the Transportation Research Board Record, 1986.

25. West, T.R., Johnson, R.B., and Smith, N.M., "Tests for Evaluating Degradation of Base Course Aggregates," National Cooperative Highway Research Program, Report 98, Highway Research Board, 1970.